Instruments

'HE MAGAZINE of MEASUREMENT and CONTROL

Vol. 23 DECEMBER 1950 No. 12

:CLUDING THE *Journal of the Instrument Society of America*

ND THE *Journal of the Southern California Meter Association*

Instrumentation for anti-vibration research at U. S. Spring and Bumper Co. which enabled reduction of damaging vibration effects.

(Photo courtesy Consolidated Engineering Corp.)

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FAST! Just wet the wick... swing the instrument... read the thermometers – and a single setting of the scale shows percent relative humidity!

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FASTER, more accurate and sensitive measuring devices can't be of maximum value unless the control mechanism can act upon the measured impulses as fast as they occur. Taylor has developed a new controller and a new recorder to take advantage of faster measuring devices, such as TRANSAIRE Temperature and Pressure Transmitters and the Aneroid Manometers for Flow and Liquid Level. These individual developments, each designed to take advantage of the other's superior performance, are now available in a complete system. The result is unprecedented quality of process control.

1. FASTER MEASURING INSTRUMENTS. Taylor's TRANSAIRE, force-balance temperature or pressure transmitters, created new standards in the measurement of *changing or dynamic* temperatures and pressures. TRANSAIRE, with derivative action (SPEED-ACT*), transmits temperature changes with unbelievably fast accuracy. Other advantages: Temperature and barometric compensation; Interchangeable unit construction; Standard 3 to 15 psi output air pressure. On pressure applications, range spans of 20 and 40 psi available throughout range limits of 35 to 415 psia.

2. FASTER CONTROL with *ability!* Taylor's new TRI-ACT Controller combines a wider range of response adjustments, an increased capacity relay air valve, and a *new control circuit*, to take advantage of the faster measuring systems. This new force-balance controller permits 4 times faster reset rate and 4 times faster rate action (PRE-ACT*) than conventional controllers. It eliminates overpeaking, and gives faster recovery for load changes on pressure, flow, and temperature applications—because rate action is in *the new circuit*. The new controller is adaptable to *your* process requirements. Can be locally mounted if needed for better quality of control, or panel mounted. You make the decision!

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M. F. BEHAR, Editor

America's Survival

"All men, who conceive, invent, design, develop, build, sell, specify, apply, install, service and maintain measuring instruments, meters, gages, testers, counters, computers, automatic inspection devices, automatic controllers and all their related devices and accessories are brothers . . . making better things for more people, eliminating repetitive drudgery and making our world a better one . . ." AND NOW, AS BEFORE, HELPING TO DEFEND THE FREE WORLD.

IT has been the custom of this page, in most December issues since 1933, to review and sometimes to predict. This is the end not only of a year but of a decade and of a half-century. What an occasion! But the world situation compels a departure from custom. So do certain internal conditions in this country. This is being written two days after General MacArthur allegedly promised that our men in Korea would all be home by Christmas—the day after Pentagon officials explained that this was physically impossible even if they were all at Korean ports, lined up to get aboard transports. These conflicting statements have created one more difference of opinion among Stateside citizens. We belong to the group called "pessimistic"—those who believe that the enemies of our way of life will cruelly throw in more cannon-fodder to prevent an early victory of United Nations forces in Korea. We realists believe—sad as it makes us—that World Communism will prolong its war on the free world, in military and non-military ways, for years to come, because its hundreds of millions of adherents have been indoctrinated with two dominant ideas:

(1) The idea that the free world—especially our own Federal Republic—is "imperialistic capitalism" with downtrodden labor and minorities, rigged elections, and invisible governments of war profiteers.

(2) The idea that "imperialistic capitalism" wants to conquer and "colonize" their countries and make them its slaves.

Therefore, it seems to us, it has become a question of the SURVIVAL of America and other free countries. Most Americans are agreed on the need of Defense; there are many shades of opinion as to how much we should re-arm, also as to HOW we should re-arm.

It seems to us that science and technology have already provided the answer. America must not and will not rely on masses of men, but will save the precious lives of her young men by relying on (1) accurate instruments of detection, (2) accurate means of interception and (3) accurate long-range weapons. Even more than in the second world war, instruments and instrument-like devices must be America's military might. Most of them have been developed. Now they must be produced in great quantities. PRODUCTION is the task. PRODUCTIVITY is the means of accomplishing this task in minimal time. The functions of instruments and of Instrument Men thus become of supreme importance. These functions have been listed here before; they are listed again, so as to serve as a check-list whereby each *Instruments* reader may evaluate his own contribution to the Defense Effort:

1. Minimizing the sum total of human drudgery, especially in eliminating repetitive operations and particularly in automatic gaging, inspection, computation, etc.;
2. Creating new and better kinds of jobs;
3. Bettering working conditions;
4. Labor saving in the sense of increasing *productivity* bringing about higher real wages and lower real prices.
5. Fuel saving and electric-energy saving;
6. Materials saving;
7. Prolonging the service-life of processing equipment;
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9. Accelerated modification of processing equipment, even to scrapping present equipment in acceptance of the oft-repeated preachment "Design controllability into production units!";
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Notes *on the* Care *and* Use *of* Electrical Instruments

By FRANK D. WEAVER, Electrical Instruments Section, National Bureau of Standards, Washington, D. C.

This article presents notes on precautions that should be observed by users of electrical instruments to enable them to achieve greater accuracy in measurements and to extend the useful life of their equipment.

I. Introduction

FROM the performance and general appearance of most electrical instruments coming to the National Bureau of Standards for standardizing tests, it appears that their users generally employ the best practices in using and handling their measuring equipment. However, instruments occasionally come to our laboratory with bent pointers, damaged coils, dirty and corroded contacts and other evidences of abuse. Had certain precautions been observed it is not likely that these damages would have occurred. The following notes are given with the express purpose of aiding personnel in (1) achieving more accurate and precise measurements, (2) increasing the useful life of instruments, (3) decreasing the cost of maintenance, and (4) promoting safety. The items included are those that, as indicated by the writer's experience with laboratory personnel and with instruments, are most likely to be helpful to individuals who use electrical measuring equipment.

II. General Precautions

Certain general precautions should be observed in every laboratory using electrical equipment. These may be roughly classified into two groups, those pertaining to (a) the general circuit, and (b) component instruments.

A. The Circuit

In making connections for a test, see that contact surfaces are clean, that nuts or binding posts are tightened firmly, that wires or cables have sufficient cross-section for the current in the circuit, and that insulation is appropriate for the voltage in use.

Sliding electrical contacts on apparatus such as bridges, resistance boxes and potentiometers should be cleaned occasionally with a dry cloth or a solvent such as varsol or benzol. If the pressure between the contacting surfaces is high, white vaseline may be used as a lubricant to reduce wear and oxidation at the contacts. For light-pressure contacting surfaces a high-grade light oil, such as Marcol, may be used with beneficial results if the contacts are cleaned periodically and only a small amount of oil is applied. In case the contact pressures are so high or edges so sharp that undue wearing is taking place at the contacting surfaces, corrections or adjustments should be made to alleviate this condition.

The laboratory worker is reminded that some of the common cleaning solvents such as benzol and carbon tetrachloride are highly toxic. Such solvents should be used only in small quantities and then in well-ventilated areas. One should not inhale the fumes or let the fluid come in contact with the skin. Some chlorinated solvents, such as carbon tetrachloride, contain traces of free chlorine which, in the presence of water, will form hydrochloric acid. Such solvents in general should not be used on electrical contacts because of the danger of subsequent corrosion from this acid residue.

Only rosin or rosin-in-alcohol should be used as flux for "tinning" and soft-soldering parts and wires in circuits in electrical instruments and apparatus. Most of the prepared fluxes contain acid or other corrosive ingredients that are destructive when used on components of delicate instruments. Surfaces to be soldered should be thoroughly cleaned and heated. Silver solder should be used when soldering manganin or for joints in which a solder connection is under stress.

Leads which are attached to instruments should never be left hanging down over a table, stretched between tables or across the floor where they may be accidentally caught with the hand or foot and the instrument pulled to the floor. They should be twisted in pairs to each instrument to reduce the effects from magnetic fields produced by current in the leads.

For measuring alternating currents of 25 amperes or more, the use of a current transformer with suitable primary ranges and a 5-ampere ammeter is generally preferable to a self-contained ammeter. This aids in keeping heavy-current leads away from the instrument and isolates the measuring instrument from the possible high voltage of the supply circuit. One multi-range current transformer with one ammeter can be used to replace a number of separate a-c. ammeters. The transformer should be tested to determine the ratio factor for its various ranges with its ammeter as a burden if the highest accuracy is desired. There are multi-range a-c. ammeters on the market with built-in current transformers that have proved very satisfactory. The primary of a current transformer should never be energized unless there is an ammeter or some other low-resistance burden, such as a shorting link, across the secondary. Neither should the secondary be opened while the primary is energized. Otherwise the secondary winding may have sufficiently high voltage induced in it to endanger insulation or the safety of personnel. There is also the possibility that the magnetic condition of the core will be changed and alter the ratio and phase angle until the transformer is thoroughly demagnetized. This condition may also happen if direct current flows through the windings. If the secondary is left open for some time with the primary energized, overheating due to the greatly increased iron loss in the core may damage the insulation.

A potential transformer with a voltmeter connected to its secondary should be used for measuring alternating voltages in excess of a few hundred volts. As a safety precaution the secondary (115-volt winding) should be grounded at one point. For highest accuracy the transformer should be tested (ratio and phase angle determined) with the burden of its circuit.

An observer in doubt about a particular setup or the use of a given instrument should inquire until the needed information is obtained. Before a circuit is energized, check all components to make sure that connections are properly made and that ranges are high enough for the magnitude to be measured. Protective resistors should be inserted where necessary. If feasible, the voltage applied should have a low initial value and then be increased gradually to the desired value.

When opening a circuit connected to electrical equipment, it is generally advisable, where possible, to reduce

the supply voltage to a low value before throwing the supply switch or circuit breaker. Remove conductors or leads to equipment one at a time, making the first break at the power source terminal and next remove the end attached to the equipment. This latter precaution applies when unplugging from a distribution board to a subpanel as well as when disconnecting an instrument, such as a voltmeter, from a line, or a standard cell from a potentiometer. The reverse steps should be taken when placing equipment in a circuit. Some careless observers, when taking an instrument out of a circuit, disconnect the leads at the instrument terminals, remove the instrument, leave the free ends of the two leads dangling while the other two ends are connected to a source of power. This is a dangerous procedure. Power circuits are ordinarily protected with fuses or circuit breakers and switches, but these protective devices do not guarantee that instruments and other equipment will not be damaged if the circuit is shorted by the careless handling of leads or switches.

Laboratory personnel should be particularly careful when working with equipment from which there is a chance of electrical shocks. Currents as small as 10 or 20 milliamperes can be dangerous to life, depending upon such factors as the current path through the body and physical condition of the victim. The value of current will depend upon the resistance of the body and the applied voltage. Under certain conditions one may receive a fatal shock from equipment that operates from the usual 110-volt circuit. If the hands or feet are damp when contact is made, the body resistance may be low enough (11,000 ohms or less) to permit a dangerous or fatal current. Such an electrical shock may be received if one touches two separate metal components of a piece of equipment, or one metal component and a grounded object so that a portion of the body acts as a parallel path to the electrical circuit. Exposed metal parts should be insulated from the wiring of a piece of electrical equipment (motors, drills, soldering irons, etc.) but sometimes, because of worn or defective insulation, the conductor comes into electrical contact with the exposed metal. The cases of some equipment are provided with ground terminals and if properly connected will protect the operator from the hazards of electrical shock.

B. The Instrument

Multi-range instruments are desirable for some applications. Many such instruments show up for repairs with bent pointers and damaged coils because users have not been careful to set the range switch in the proper position before closing the circuit. When some circuits (for example a bank of tungsten filament lamps) are initially closed, the cold-state resistance may be low and the initial surge of current rather high. An ammeter placed in such a circuit to measure the steady-state current may be overloaded by these initial high currents and result in a bent pointer. It may be advisable to short out the ammeter during the period of high initial currents. In a similar way the insulation of the coils of a voltmeter may be damaged by voltage surges or by distorted waves that have a high peak value, say as much as five times as great as the rms. value to which the instrument responds. This latter situation is especially dangerous for electrostatic voltmeters. A protective resistor should be placed in series with the high side of an electrostatic voltmeter to prevent "burning up" the instrument spring in case of flashover between its plates.

In the laboratory one frequently uses a suspension-type d-c. galvanometer in connection with bridge and potentiometer measurements. Ordinarily these sensitive instruments are used to determine voltage balances between the arms of a bridge or potentiometer and do not directly measure electrical magnitudes. Such an instrument should have the sensitivity necessary for the precision desired, should have a short period, and should be slightly underdamped in its circuit. If its sensitivity is higher or its period longer than necessary, time will be wasted in getting balances. Since galvanometers are made of delicate parts they should be handled with great care and be protected in a circuit by suitable switches and resistors.

Make it a practice to handle all instruments with care; treat those used as laboratory reference standards with special respect. Pivoted instruments should never be placed or left where they may be exposed to vibrations. One severe shock, such as a hammer blow on a bench or table where instruments are resting, can permanently damage their pivots and jewels.

In making adjustments or repairs on instruments, bear in mind that only the manufacturer is really well qualified to make MAJOR repairs. If it is necessary to open the case, it should be done in a room where there is a minimum of dust and in an area where there are no iron filings.

When instruments are not in use, they should be stored in cases or cabinets free from dust, acid fumes, excessive heat, moisture and vibration.

Shorting the terminals of a galvanometer or microammeter by means of a small conductor before such instruments are moved heavily damps the motion of the moving parts and helps to prevent damage. Locking devices are sometimes provided for moving systems to protect pivots and jewels or suspensions from shock while the instrument is in transit; make proper use of them.

Instruments that are being prepared for shipment should first be wrapped in heavy paper to exclude dust and dirt, surrounded by a cushioning material such as several inches of excelsior, and carefully and securely packed in a strong, properly labelled box. The top of a wooden packing box should be fastened with screws (not nails) to avoid damage resulting from blows with a hammer or nail puller. It may be advisable to invert the instrument in the shipping container so that the upper instead of the lower jewel and pivot receive any damaging blows that occur in shipment. If this is done, the box should carry a "This Side Up" label. These precautions aid in protecting delicate lower jewels and pivots from injurious mechanical shocks during transit.

Precautions should be taken to prevent marring or scratching the finish of an instrument lid or case. Such defacing may occur if an instrument is placed near a hot rheostat or an inverted lid is carelessly pulled along a rough surface. An occasional cleaning of the surface of an instrument case is advisable in order to restore good appearance, as the better the appearance the more respect it is likely to receive.

A relative humidity of less than 65 percent and a temperature of 25 C. are desirable for the air of a room where instruments are to be used. If the air is too humid, moisture may condense on insulating surfaces between resistors and act as a high-resistance shunt or in effect reduce the total resistance of that part of the circuit. This effect is ordinarily more noticeable in high ohms-per-volt instruments. For extremes of humidity, moisture may be absorbed by or evaporated from the insulating fibers surrounding fine resistance wire, causing the threads to change dimensions, thus exerting pressures and stresses on the fine wire and altering the resistance.

It is a good practice to compare working instruments against reference instruments at least once a year. If high precision of measurements is needed, the instruments should be checked against reliable reference standards or sent to a measurements laboratory where precision tests may be made. Such tests will reveal changes in the accuracy of instruments.

Most instrument companies occasionally issue instruction manuals, bulletins and catalogs for the benefit of their customers. These ordinarily give valuable information about their instruments, with diagrams showing how to connect them in a circuit. It is well to consult such manuals in addition to handbooks, textbooks and other useful sources of information.

III. Sources of Error (Instruments and Associated Apparatus)

A knowledge of the common sources of error in instruments and associated

apparatus may be helpful in eliminating certain errors of measurement and increasing the accuracy of results.

Some of the conditions that may interfere with the normal turning of the moving system of an instrument are: a warped or loosened paper scale, thin fibers projecting upward from a paper scale, iron filings in the air gap, a bent pointer, a bent damping vane, a flat pivot, a broken jewel, or a moving system too tight or too loose in its jewels. Each of these possible sources of error should be corrected and the instrument retested where necessary before use if highly accurate results are desired. Obstructions can usually be detected by a "jumping of the pointer" as current through the instrument is slowly increased or decreased to deflect the pointer upscale or downscale. Occasionally during this test, set the pointer to a scale mark and tap the case lightly: pivot friction will be revealed by a slight change in pointer position.

Tapping the case of an instrument while it is being read is usually unnecessary if the instrument is properly constructed and in good condition. However, when slight friction is present from any cause, its effect can usually be temporarily minimized by gently tapping the case. Hard tapping may result in damaged pivots and jewels.

Errors resulting from friction and from mechanical unbalance may be expected if a portable instrument, designed to be operated with the axis of the moving coil in a vertical position, is read while the instrument is so placed that this axis is inclined from the vertical or is in a horizontal position. In general it is good practice to use an instrument with its moving-coil axis only in the position for which it was designed.

Parts of moving systems, including pointers of instruments, tend to vibrate at certain frequencies where they are mechanically resonant. Ordinarily, at the frequency for which the instrument is designed, this should not be expected as the maker tries to avoid this in his design and construction. This phenomenon is revealed by erratic pointer movements, pointer widening or blurring, and sometimes by a rattling noise. Errors should be expected if the instrument is read under these conditions. It is possible to change the resonance frequency by changing the balance weights and rebalancing the moving system.

Some instruments show inherently large zero shifts: After the moving system is deflected up-scale for a few minutes, the pointer does not return to its initially set zero position when the circuit is opened. The observed shift may generally be explained on the basis of inelastic yield in the springs. Such shifts constitute a source of error for which it is not practical to apply a correction. The only remedy if the shifts are large is to have the spring replaced by the manufacturer.

Poor electrical contacts at the switches or in any part of a measurement circuit are a source of considerable annoyance to an observer. In instances where this condition cannot be alleviated by cleaning and oiling the contacts, it may be necessary to have the contacting surfaces plated with nickel, silver or gold. For rugged service, where high currents and greater wear due to higher contact pressures are involved, a silver inlay in the contacting areas has proved highly satisfactory.

An electrical instrument may give inaccurate values because of errors in the original scale calibration. In other words, the cardinal points on the scale may have been improperly placed by reason of uncorrected errors in the test equipment or in procedures used to locate lines on the scales. An inspection of the scales of some instruments reveals a noticeable inequality in the spacing of adjacent subdivision marks. An observer should not place much trust in the indications of an instrument that has an erratic and carelessly-drawn scale.

To provide the greatest reading accuracy, a portable instrument should have a good scale, a knife-edge pointer and an anti-parallax mirror. The knife-edge width should be about equal to that of the scale division marks, and not greater than one-tenth of the distance between successive scale divisions. For such an instrument an experienced observer should be able to estimate the pointer indications to better than ± 0.2 scale division. With a laboratory standard having the major scale divisions subdivided into fifths by means of diagonal lines intersecting six concentric arcs, one would be expected to estimate to about 0.05 of the major divisions. Instruments that do not have anti-parallax mirrors are subject to rather large reading errors.

When a wattmeter is initially inserted in a circuit for the measurement of a-c. power, it is a good practice to put an ammeter in series with the current coil and a voltmeter in parallel with the voltage coil. This precaution is advisable because it is possible for either or both coils to be damaged by overload and yet the pointer may not indicate a full-scale reading since a wattmeter measures watts ($VI \cos \theta$). To avoid the errors caused by electrostatic effects resulting from differences in potential of the two circuits of a wattmeter without a common connection, the $\pm$ voltage terminal should be connected through a voltmeter to the $\pm$ current terminal.

Errors may result from (1) electrostatic forces, and (2) leakage currents, if the moving system of an instrument is at a different voltage from that of its case or panel. Correct electrostatic shielding will eliminate this source of error. Static charges on the glass window or case of an instrument may also cause errors in pointer indications. The effect of a static charge, such as one arising from rubbing the glass with a cleaning cloth, may usually be eliminated by blowing one's breath on the affected area. Trouble from the accumulation of static charges will be more frequent at low humidities because of increased insulation resistance.

Insofar as possible, one should avoid locating instruments in an area where there is a strong magnetic field or adjacent to large masses of metal. Strong fields may be encountered near current-carrying conductors, transformers, Variacs, and even other instruments. Pointer indications of some unshielded portable d-c. instruments may be in error by as much as 2 percent when the instrument is read while resting on a table having a sheet-iron top. Errors resulting from stray fields, eddy currents and the shunting effect of nearby sheets of iron, are generally much less for shielded instruments than for unshielded ones.

A panelboard instrument should not be inserted in a steel panel unless it has been calibrated by the manufacturer for use in such a panel.

There is a tendency for the magnets of d-c. instruments to become weaker with time if they have not been properly aged or conditioned, thereby weakening the flux in the air gap. Such a tendency is indicated when periodic tests show that an increasing value of the measured magnitude is required to deflect the pointer to a given scale mark, other factors remaining constant.

In making measurements with ammeters, voltmeters, and wattmeters, it is well to remember that there may be considerable power losses and voltage drops in the instruments as well as in their leads. These must be taken into consideration in precise measurements.

Voltmeters requiring 0.1, 1, 10 and 100 milliamperes for full-scale deflection are in common use. Before a voltmeter is placed in a circuit, one should consider the effect of the current losses of the instrument upon the circuit. Voltmeters having current losses of 0.1 milliampere are desirable for some applications; however, one that requires 10 milliamperes for full-scale deflection is likely to have more rugged components and therefore is preferable where current loss is not an item of importance.

When carrying rated current, shunts and resistors in some instruments are required to dissipate a considerable amount of heat. Unless the resistance material was properly annealed by the manufacturer and has a low temperature coefficient of resistivity, changes in resistance with use may be expected. These changes, accelerated by heating which occurs when the resistor carries rated current, may produce significant errors in instrument indication. Adequate provisions have not been made in some instruments and equipment for dissipating their large heat losses, and this may result in excessively high temperature when in use.

Some types of instruments not properly compensated for changes in temperature may be in error by as much as 0.4 percent per degree Centigrade. An instrument will normally be at least partly temperature compensated, so the coefficient is more likely to be 0.1 percent or less per degree Centigrade. Since most instruments are calibrated for use at 25 C., for precise work it is best to allow them to reach temperature equilibrium in a room maintained at this temperature. This is especially true for thermocouple instruments because they have rather large temperature coefficients. If this precaution is taken, it will not be necessary to apply temperature corrections to pointer indications. It may also insure against errors arising from an unsuspected difference in temperature of the components of an instrument.

Lamps used for scale illumination radiate considerable heat and, if placed too near the coil or spring, may increase the temperature of these components and thereby produce considerable error in the pointer indication.

The values indicated by moving-iron and rectifier-type instruments may be in error by several percent if used on direct current or if used on alternating current at a frequency other than that for which they were designed by the manufacturer. Rectifier instruments are generally calibrated for use on a pure sine wave and their readings may be considerably in error if used for measurements in which the wave-form is distorted.

Electrodynamic (except those having iron cores or built-in transformers), electrostatic, and thermocouple instruments are designed for use either on direct current or on alternating current within specified frequency ranges. The mean of values corresponding to the two directions of current should be used when measuring direct current with either of these three types. When alternating current is measured, the frequency should lie within the range for which the scale was calibrated. Ac.-dc. differences for these three types are ordinarily rather small at power frequencies. However, for measurements of the highest accuracy, it may be desirable to have these differences determined.

Switchboard shunts of large current rating (1000 amperes or more) should be tested in position with the current and potential terminal connections normally used. A test in any other position is not likely to duplicate the current distribution through or the heating of the shunt encountered in normal use and may give values of current that differ from those for normal connection by as much as 2 percent.

Standard cells must be used with care. Unlike electrical instruments they give no visible signs of electrical abuse. They are designed for use as standards of emf. only and should be properly connected to a potentiometer. The unsaturated type of cells are generally used in laboratories. Even a small current drain for a short period of time (100 microamperes for 5 minutes or more) may temporarily impair the usefulness of such cells. If used in potentiometers where highly accurate measurements are desired the cells should be tested periodically. It is sometimes advisable to enclose them in thermally insulated boxes to eliminate errors that arise from sudden changes in temperature or differences in temperature between the two legs of the cell.

A millivoltmeter in combination with a pair of leads and an external shunt (or a group of shunts to provide a number of ampere ranges) is sometimes used for measuring direct currents. To get reliable results, it is necessary to use the particular leads (or leads having equivalent resistance) with which the millivoltmeter and its shunts were tested. Since the millivoltmeter may have a resistance of only a few ohms, it is apparent that a small change in resistance of the leads or their contacts may cause an appreciable error in measurement.

IV. Measurement Procedures

When making a test, record on the data sheets all pertinent information about the test and the equipment used. A wiring diagram of the test setup, date, humidity of air, room temperature, duration of warm-up period, makes, models, ranges and serial numbers of instruments and equipment used should be listed. Unusual temperature rises as well as defective or unsatisfactory performance of any equipment should be noted. The record should be sufficiently detailed to permit an accurate appraisal of the test results or a later duplication of the setup to permit a satisfactory experimental check. Test records should be complete, in ink, and on a good grade of paper so that they may be filed for future reference. The records should be made unless the observer is certain that they will have no future use. Inadequate test data may be a source of genuine embarrassment at some later date.

Before an observer reads an instrument he should make sure that the scale is properly illuminated. This is of considerable importance for precise readings or if errors resulting from fatigue are to be minimized where consecutive readings are to be made over a period of time. A hand lens having a magnifying power of 5 is a helpful aid in getting accurate pointer readings.

It is a good practice for an observer to read and record the pointer indications of an instrument in divisions estimated to tenths (on the appropriate scale of a multi-range instrument) rather than in measured units. The correction table for a given instrument should also be expressed in divisions. There will be a minimum of confusion if the formula $I+C=T$ (indicated reading plus correction equals true value) is used in applying corrections. The true value (in divisions) may then be converted to measured units.

Assuming that an observer can estimate a pointer deflection on a 100-division scale to 0.2 division on any part of the scale, a reading error of 0.2 division at the 100-division point will be 0.2 percent of the measured magnitude, whereas a reading error of 0.2 division at the midpoint of the scale will be 0.4 percent of the measured magnitude. On the same basis the error at 20 divisions will be 1 percent of the measured magnitude. It is apparent then that if one is to minimize reading errors, only about the upper half of a scale should be used. For lower values of the measured magnitude, one should make use of a lower range instrument.

The laboratory and its equipment should be restored to order after completion of each job. Instruments and other equipment should be returned to their assigned cabinet or storage space where they will be protected and can be readily located by the next user. An instrument that has been damaged or found to be defective should be properly labelled "To be repaired," and should not be returned to its usual shelf space. The person in charge should be notified and steps taken to repair or replace the damaged part.

V. Conclusion

In conclusion then, to get the most out of an instrument one should take advantage of the information in manufacturers' instruction manuals and any other good sources. The proper connections, correct applications and limitations should be known for each piece of equipment. Such factors as frequency, wave-form, temperature, and stray fields, must be given careful consideration. The instruments should be tested periodically, and when in use precautions should be taken to eliminate or to correct for all possible sources of error. The life of an instrument will be materially increased if a little forethought and respect are given at all times in its care and use.

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Some Instruments *in the* Oil Laboratory

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WE are interested in instruments either to improve the process and save money or improve the product so as to make more money. But many of the instruments that we see in research laboratories never get into that picture at all. For some of these instruments there is never enough market so one can get the money back out of a development. For instance, consider bottom hole gages or refractive index instruments. It is difficult to make such an instrument pay; however, such developments are necessary because we need the instruments and will need them more as time goes on.

Perhaps one of the earliest instruments developed at Gulf was the bottom hole gage. There are five or six designs on the market. The earlier ones hovered along the lines of the ordinary pressure gages, using the Bourdon tube. In fact the Amarada, which is one of the oldest, was a coiled Bourdon tube, now often found in recording pressure instruments in the refinery or in the industrial establishment. The drawback to the Bourdon gage (and I used to make gages at Crosby nearly thirty years ago) is that it has no power. The minute an indicating device is installed, part of the accuracy is destroyed. The gage we worked on is based on the corrugated bellows. The beauty of that device is that it is equivalent to a frictionless, leakless piston of large area, and it has anywhere from 150 to 250 times the available energy of a Bourdon tube. Thus when the indicating or recording device is added, it does not decrease the accuracy so much. Most of these gages (for instance the Amarada which is still in great use, Humble's packed piston type, and two or three others) ran about plus or minus one percent accuracy. We need much better accuracy in obtaining bottom hole pressures. We are looking for deviations of about two pounds plus or minus. As the well is drilled deeper and the pressure goes up, the required instrument precision is rising all the time; and it gets pretty tough when some of these jobs require a 6,000-pound gage; it seems that a 10,000-pound gage will be required in the future. With the bellows and that tremendous multiplication of energy, we have consistent results which are better than one-tenth percent. This means in a 2,000-pound gage we are within the range all right. It is a little tough as the pressure goes up because the precision required is about ten times greater than most of the gages that have been used. All the others can and probably will be improved, but that kind of a gage, used on the end of a line in the hands of a roustabout in the oil fields, is more precise than any of the high-pressure test gages ever used in the laboratories until very recently. We have a few good Bourdon gages with large tubes that have very good precision; but when a bottom hole gage has to go down into the hole five thousand or ten thousand feet on the line, its handling is somewhat rough. Another difficulty is that the dimensions are so restricted. There is all the length needed but no width. The present gages are an inch and a quarter to an inch and three-eighths in diameter and five or six feet long. It is quite a nice mechanical job to pack in the mechanism to take an accurate enough record of required data.

The next one that came along was the bottom hole sampler for getting crude oil and gas samples at the bottom. About half a dozen different samplers have been tried. The one we experimented with has about the same dimensions as the gage and is operated by a messenger running down the line, a go-devil of a half pound or so in weight. Valves at top and bottom are tripped from the open position to the snap-shut position, and even then we have to be careful; if we are to get the sample in the condition at the bottom we must not have very much shock. Therefore it is arranged so that the bottom and top valves will close at slightly different times so there is no shock on the oil. We found the way to get pressure on the sampler was quite simple. The volume of the sample must not change; it must be at the original temperature because some of these wells are fairly hot at the bottom (250 F.); coming up out of the hole the gage pressure will fall as temperature decreases. If there isn't much gas, the sample may have no pressure on it at all when it gets up to the top; it has cooled enough to take the pressure off. There must be a recording thermometer in order to find out what the temperature was when the sample was taken. The bottom hole samplers run about $1,000 apiece, and auxiliary apparatus to handle the sample runs anywhere from $2,500 to $3,000. It is true only one set of auxiliary apparatus is required per given location, and there might be a dozen samplers which are served by this auxiliary set.

The next development which was quite elaborate was what we call the P-V-T machine. All of the oil industry is interested in finding out the condition of the oil at the bottom of the well, and it would be very convenient if we could discover the condition from the gas separator and the oil that goes to the tank and predict what was going on at the bottom. This P-V-T machine is equipped so it will take samples from the bottom hole sampler without changing pressure. We can then test the viscosity in a rolling ball viscometer at the temperature and pressure at the bottom of the well. After this test we can transfer it into another part of the apparatus and start withdrawing gas to find out what the solubilities are—quantity of gas released as pressure is dropped—a very important thing for predicting flow life and the total history of the well. In addition to that we can also put in samples from the separator and tank and synthesize them and see if they come out with the same answer. That apparatus cost about $8,000 to build a year ago, and it probably costs more now. There must be a lot of benefit from a piece of apparatus that costs $8,000 to make it pay. We have made five of these so far.

We are in a little different position from many of the other oil companies in that we have an extremely complete instrument shop at the laboratory and can build anything we want. The designer never knows what his final device is going to look like; he can make mistakes in laying out, and if the shop is in close contact the design can be changed and fixed before the money has all been spent. If you have to contract the job to an instrument company, it really costs you money to make changes in the middle of a design.

The next group, a variety of instruments for finding out the contours of the layers of igneous rocks which tell us about where oil ought to be found, was designed by the geophysicists. Years ago we started with the torsion balance which was a foreign-built instrument, then worked through the gravity pendulum. The gravity pendulum consisted of two pendulums made of fused quartz and sputtered with platinum on the outside to dissipate electrical charges which will gather, even swinging in a vacuum. They start off with about a centimeter and a half swing, which at the end of twenty minutes would drop down to about six-tenths of a centimeter; there was not much friction loss. Those gravity pendulums cost about $6,000 apiece at that time, and they would cost twice that now. We made seventy of them. Their precision was of the order of one part in ten million. The geophysicists now have the gravimeter type of instrument which depends on the tendency of a specially made spring to uncoil as it is loaded. They multiply the rotations eleven times optically. That instrument has a precision of one to one and one-half parts in a hundred million. These instruments are also expensive. If there are ten or twenty parties out doing explorations, each one has to have one of these instruments.

My company and the Navy simultaneously worked out from the submarine detecting devices developed during the war, a device for measuring magnetic field in the earth. It was called a flying magnetometer. That is nothing but a highly developed magnetometer which can be flown behind the plane in a so-called "bird" on the end of a cable. The

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in trument is so well developed now that it sends all its signals up to the plane and takes records of everything that goes on. The plane is flown in a pattern over the country and twenty to forty times as much area can be covered as by a ground party. Of course that is going to pay well. These instruments cost around $8,000 apiece. There are about eight sets of beveled gears in them which are difficult to make accurately. They are made with no backlash and can work in either direction without lost motion, sufficiently accurately to fit the purpose. The cost of exploration is going to be considerably cut down where this flying magnetometer can be used. Part of this development came from work done during the last war on the Azon and Razon bombs. In the early days of bombing, the formation might make four passes over a bridge with a group of four planes and drop one or two clusters of bombs from each plane and perhaps hit the bridge. With the Azon and Razon bombs I have seen one pass from one plane put three out of four bombs on the bridge.

Another older instrument is the well weigher, of which we have several varieties on the market now. A few years ago we were greatly puzzled by the fact that sucker rods kept breaking when, according to our ordinary methods of engineering figuring, the stresses on the rods were not enough to break them. What was happening was that we got out of range of ordinary engineering into what we might call acoustic stresses—resonances and bounces. The thing was to find out what were the actual stresses in the rods. The first thought is to use mechanical methods, and one of the earliest of those was devised by Westinghouse. There are several on the market, all good, using the circular measuring rings as a suspension for the sucker-rod string and measuring the deflection from the ring by multiplication mechanically to draw a chart. We worked on an electric strain gage type which also was pretty good, in which the elongation or compression of an aluminum tube was measured by the change of gap between the two magnets so we could read the change in permeability of the system. That drew a photographic diagram. That is probably not so well liked in the field because they don't like all the bother connected with films if they can get a pencil drawing on the card much quicker and easier. But those instruments both ran about the same accuracy. They are giving stresses within about one percent. Not only did we find that the so-called resonance stresses added on to the ordinarily figured stresses in the polished rod were doubling and tripling the strain on the rods; we discovered why they occurred. We applied this instrument to cable tool drilling to see what it was that made the blow right or not. Of course, the driller used to put his hands on the cable and could tell pretty well. When the wells get deep, the driller's hand is not quite as accurate as that. We need to know what is happening on the bottom in a 12,000-foot well (or deeper) because the shock in the cable is now distorted, and you cannot find out easily. A change in drilling speed from 20 strokes a minute to 20.3 could halve or double the strength of the blow. That is how sensitive it is. The speed must be on the resonance point of the system and that resonance changes with depth and size of the rods or cable being used. Drilling could be at the highest rate with the use of an instrument like this for finding out where the peaks occur. That information is extremely useful and saves money, which is the reason for a research laboratory.

Most of the engineers are a little bit disgusted with the chemists because they are always playing with the SUS method of finding viscosity. This exemplifies the mania of both engineers and chemists for getting indices that they don't need. Saybolt seconds are no good to us in that form; we have to translate them back into centistokes or centipoises in order to use the value in formulae. In the Saybolt viscometer an orifice is used; the entrance effects are high and the viscosity effects are low, so when getting down to limpid materials like water, or particularly alcohol and gasoline, the instrument is no good. It is on a very sharply curved portion of its curve or calibration where the entrance effects are overshadowing the viscosity effects, which is not very good. Consequently, the Saybolt instrument cannot be used for alcohol, gasoline, or anything thinner than water; and it is not very good when near water. We have been trying to get up viscometers of the pipe style because the mathematics of finding the viscosity from the pressure drops is easy. With such a viscometer, everything from a fairly thick mud or grease down to a thin liquid can be measured, and in the same instrument, which is handy. We built one which can give us prompt readings and is very useful on mud. People were using all sorts of viscometers, intended for Newtonian liquids. A single point viscosity on a material like mud is useless, because the viscosity is not a constant the way it is with a true liquid. The viscosity varies with rate of shear because mud has thixotropic properties. To find out how a grease behaves (also thixotropic), viscosity readings are taken at several speeds of flow. When that information is obtained, the whole behavior of the mud or grease can be predicted and the hydraulic formula then becomes very useful in computing the pressure loss going down the drill stem and up the hole, needed for predicting the pressures required of the pumps. It opens up a tremendous field that is useful on grease-lubricated bearings. If the same thing can be done on a grease, the instantaneous viscosities can then be substituted in the hydraulic formula and the load-carrying capacity of a grease-lubricated bearing calculated.

Bearings are constantly being tested. The newer bearing test machines appear to be better than the earlier ones. At any rate, some of the interesting ones we developed showed the highest accuracies of any kind that had been built so far. They are the cradle-type machines; but instead of using knife edges, we have used the Cardan hinge. This is a thin strip of metal which is flexed as the cradle swings, working near the null point so as to elide the spring effects. The advantage of the Cardan hinge over the knife edge is absence of friction; the knife edge is always rounded or it would not carry any load. The greater the load is, the larger the rounding is. Consequently, it has a friction loss; and dirt can get in between the knife edge and seat to destroy accuracy, which will not be noticed until the scale is calibrated. This cradle bearing machine which we built has been shown to be very sensitive. We can get precise friction coefficients of bearings, and we have found many cases, that were not discovered on the earlier machines, where the friction coefficient is below 0.001. Actually, the best bearings should always be down that low if designed right, and if the oil being used is right for the speed.

We then moved into ball bearing testers. The first of these was to find out why the wheel bearing greases are good or bad. Nobody knows much about greases. The chemist will not know a thing about a grease he has designed until it has been mixed up and applied in the bearing. So we developed this ball bearing machine originally to test wheel bearings and see how the grease behaved in them, and that developed into a device for testing commercial ball bearings of any kind. Here we can vary load, speed, temperature and the kinds of grease that are used. To indicate how sensitive such a test can be, one make of bearing must be adopted and then the shaft fitted so that the stretch on the bearing provides the same clearance in each bearing. In other words, a Class A or B tolerance is not good enough to repeat the test. If the bearing does not fit, the test will be on the bearing instead of the grease. With that device, we have begun to find out something about greases—what makes them good or bad—because temperature, load, and speed can be varied. There are a number of bearing testers on the market which do not load the bearing. There is no problem lubricating a ball bearing until there is a load on it. The time it needs a lubricant is after it is deformed by the load. Therefore, a device that tests a bearing grease and a ball bearing with no load is merely testing the chemist's part of it—whether the lubricant is going to separate, oxidize, or leak out. It does not indicate whether it is lubricating the bearings at all. We must go further than that. Some companies are building jet turbines and have high-speed devices—anywhere from twelve to twenty-five thousand revolutions per minute—and they want a lubricant that will operate at 600 F. That is very near the cracking point where almost all hydrocarbons will break down. But that is what they want, so we ran bearings at twenty-five thousand revolutions per minute at 600 to 800 F. and found out what greases will do under those conditions. It occurs to me they might cool the bearing and run it at a reasonable temperature, but bearings are put in the middle of the nest

of combustion chambers with no cooling. The latest design of bearing test machine is the one we are working out now. Most of the bearing test machines in the past have been able to take care of a undirectional load, which represents a very large percent of the bearings. When we get to the automotive and aviation uses, we have two other kinds of load to look after. One is the reciprocating load which is on the wrist pin and the other is the rotating load which is a combination of explosive pressures and centrifugal forces, which occurs in crankpins. Most machines designed to test rotating loads have bob weights on them. These may be dangerous because they are all adjustable and bolted, and if one is thrown off at high speed it will probably go half a mile before it comes down, taking everything in its wake. These machines give only a single rotating radial load whereas the engine may not give the same results in the bearing because it produces anything but a uniform radial load. There are all kinds of shapes in the engine; loads range from a maximum to a minimum and sometimes reverse themselves. We found that the bearing will stand more rotating load than unidirectional, and we want to know how much it will stand. In the new design the bearing is loaded hydraulically, using hydraulic cylinders and a pulsator at four points to develop a rotating field just like an induction motor develops a rotating field. We will be able to get unidirectional load, reversing or shaking load, and rotating load, all in the same machine. Any desired shape diagram may be obtained by adjusting the pulses at the four points to the right amplitude by small plunger pumps. Two pumps are used to each point. When they are exactly in phase, the maximum pulse is obtained and the load can be set by simply pumping the pressure in that part of the system up to a desired level to begin with. With that machine we can test a bearing carrying 25,000 pounds load in a device that is quite small. There is no risk in it since there are no unbalanced parts.

Another device is concerned with the proper application of oil to the bearing. For a long time Babbitt metal was used exclusively in bearings. Corroded bearings were unheard of until we got rid of Babbitt. Men in the oil field are still using a lot of it, but in the automotive field they have cadmium-nickel, cadmium-silver, copper-lead, etc., and bearings have become increasingly expensive. For the first time we discovered that oil was corrosive. We had to find out the life of any given bearing under conditions where the oil breaks down, because oxidation forms acids in the oil which attack some of the bearing metals. For a device imitating the engine, we use a pair of connecting rods out of a Plymouth or Chevrolet, mount them under a load spring device that gives them continuous load, oil them the same way they are in the engine, raise the temperature with an electric heater, and we have a test device for finding out whether or not an oil is going to be corrosive. Twenty-five hours is sufficient time to discover what the nature of that oil is going to be and how many more kinds and percentages of additives must be put in to stop the action. Then it is the chemist's job to fix up this oil so it isn't corrosive.

The reason for piston rings wearing out as fast as they do is still a problem, so we started experimenting with engines first to see if we could get some information. Fifteen minutes consideration will show that there are about thirty variables involved. We then started building what could be called the academic machine. It was built from a piece of piston ring and a piece of a cylinder. These were moved backward and forward under a load, but most of the variables were held constant. The only things to vary are speed, load, temperature, and the character of the material. These are the minimum variables to consider. We must find what variable does most damage in the engine; probably it is piston rock or piston ring dishing under loads, because rings as they come out of the engine are no longer flat when they are worn, they are always cambered. What we do in the engine is ruin the Reynolds wedge by rocking the piston the wrong way to get the wedge, and it acts as a scraper. There are two conditions in the engine which fight each other. One is, we want lubrication for the cylinder and the ring, but we also want to prevent the oil from getting up into the combustion chamber. When the ring is made so it seals completely, it will never lubricate right. The next move was the addition of a strain gage on the carriage-towing mechanism for the piece of the cylinder sliding past the ring. We think the ring is lubricating pretty well but the friction coefficient is up to about 0.10. Anyone who has ever designed a bearing knows that when friction coefficient is up to 0.10 the ring is not being properly lubricated. It ought to be not over 0.01 at the worst, and it should be lower than that. The answer is that the piston ring has never been lubricated properly yet.

We also found that the coefficient of friction increases with increasing load. When the coefficient reaches 0.15, the diagram in the strain gage begins to get harmonics in it, and, if kept there, it develops a scuff. This harmonic pattern always appears when the coefficient is up to about 0.15. We now know what can be done. We are going to try designing some rings that will both lubricate and seal. Reynolds gave us the academic theory of bearing lubrication back in 1884. The only drawback was he solved the case for an infinite length bearing which we never will have and for a lubricating material coefficient of viscosity which did not change with temperature (which we probably never will have). There is a chance we might get that one, but we certainly won't get the infinite length bearing. Therefore, we are always dealing with finite length and with variations in viscosity with temperature. A number of people—Howarth, Kingsbury, and others—have worked empirical relationships from tests to show the effect of the finite length of the bearing on the load-carrying capacity. We think we can beat that, so we built a couple of electric analogs in which we can imitate the flows with electric current. Kingsbury built one of them in the early days but not quite as complete as we are able to do now. We might find out what really is going on, and get to really calculate the situation rigorously, instead of making an academic calculation and applying a factor obtained from tests only.

The next thing we get into is cutting oils. Little progress has been made on this since 1915, simply because people have not realized just what it is they should be looking for in cutting oils. Here is a cutting edge of a tool, the tool itself very hard, the metal quite hard, in many cases up to 275 Brinell, and nobody has found out what the loads are. They certainly must be high at the edge of the tool. What is very much more important, they have been carefully pouring oil all over the tool, but they pour it on top of the chip and maybe it never gets on the edge of the tool at all. The first thing which must be done is make sure that the lubricants are getting in the place where we want them to be. There is every sign at present that in most of the shops in this country the method of putting the cutting oil on the tool is no good. The oil must be in the place where it ought to be before it can be rated. We have found some new instruments that will help out. The Solex gage idea, which was old before the Solex patent ever came out, has been used in industrial regulators for at least forty years, in one form or another. The flapper valve type of control is one example of this. The Solex gage simply feeds through a disk orifice and then through some other orifice which is being varied by the approach of work to it, and the change of pressure between those two orifices gives the dimensions you want. We finally woke up to the fact that loads can be measured by the Solex gage setup. What is being done in the cutting tools is to feed air through a disk orifice up to a cup against the bottom of a tool holder. As the tool holder flexes under the load of cutting, it deflects and records the load on the tool; it is highly accurate and so rugged that pouring chips and oil all over it does not bother it; the man working on the lathe can adjust it. That is the ideal research instrument. Feed loads can also be taken by putting another cup on the side of the tool holder and if you want radial loads on the nose, one can be put on the back of the tool holder.

Another instrument which was not new with us but was written up in Australia 22 years ago, was a method of getting temperature at the edge of the tool; no one paid any attention to it since. The tool steel in the tool is quite different from the work in all cases, so they make a good couple. To our astonishment, when we tested it on high speed steel and 3140 or 3150 chrome alloy steel, a satisfactory voltage is obtained between these two. All we do is hook up the tool as one leg of the thermocouple and the

work as the other. Care must be taken in insulating the work because with those low voltages the stray currents can be bothersome. The easiest way is to put a Bakelite nose on the tailstock and put a couple of fiber jaws on the chuck on the other end and insulate the work. Even the chips shorting across between the work and the tool holder will not alter the temperature reading appreciably, because these modern instruments work on no current by balancing the circuit. It takes an infinite conductivity to short it out, so that a chip is not enough. It is difficult to get a direct check on whether the temperature is right, but we have a good check on it from the color of the chip; with a blue chip the temperature corresponds, for example.

Those are two of the tools, but we don't know if they are enough. However, I think with that kind of instrumentation we can find out something about cutting oils.

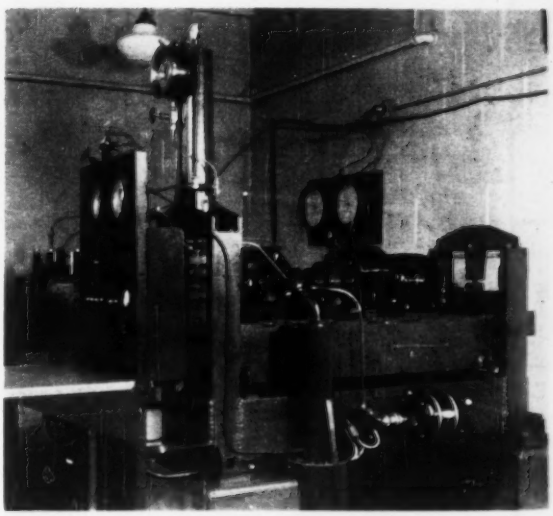
Here is another thing we found out with this setup. With the torque and temperature indication we could start improving the oil feed. For example, putting a jet up from underneath into the crack between the heel of the tool and the work definitely gave better lubrication. About a 25 percent improvement was obtained in torque and drop in temperature. It isn't the final answer, because it has not changed the tool life enough, but that is the sort of instrumentation we need to find the facts.

The next instrument is a textile spindle dynamometer which runs about 10,000 rpm. Spindles are problems because there are a couple hundred on a single mule and the starting torque is of interest because it is much heavier than the running torque. The pull is in the order of an inch-ounce, but they want to find if it is going to pay them to use a lower viscosity oil on the spindle, and whether it changes the wear. We had to design a dynamometer, consisting of four fulcrum plates holding the spindle bolster in position so it is flexible in rotation but not against vertical load nor against pull of the belt, and use another of these air cups to measure the torque. It works very well.

Now we get over into such things as fuel and oil testing for the internal combustion engine. It is surprising how many special test instruments are required to do that, chiefly because a flock of variables are always being dealt with. We designed a two-cylinder V engine to do oil testing, usually done on any single-cylinder engine that the laboratory happened to select and thought was good. The trouble with that setup is that when it is tested a universal test on the oil has not been obtained. It is just the behavior of the oil in that particular engine and it is not known if it applies to any other yet. This two-cylinder engine is flexible in every respect. We can put L-heads on it, I-heads, air cooled, separately cool the head from the jacket, we can stick thermocouples all over it, we can supercharge it; we have at last a rubber engine we can shape any way we want because we don't even know what kind of tests we ought to be making in the future yet. The trouble is in buying special engines, they cost plenty of money to begin with, they are hard to change, and they are seldom designed for this variety of changes in the test methods that are really necessary in order to find out where you are going. We have five or six running now, and they are beginning to be interesting. You can realize what it means in money when using the CUE—the Cooperative Universal Engine—designed before the war; it used full-scale aviation cylinders and cost $20,000 for the engine—about $30,000 for the total installation. There is not enough lubricating oil sold in the aviation industry to pay for many of those machines. This two-cylinder engine cost $1,000 originally, is nearer $4,000 now, but that is a lot cheaper than $30,000. Since it must be very well balanced, the V-design was taken in imitation of the motorcycle engine which is one of the best balanced engines for two cylinders which can be designed. We can get the high piston speeds without having counterbalance weights (or vibration dampeners) because they always enlarge the crankcase and that spoils the parallel with the multicylinder engine. These test engines must be designed with the same amount of crankcase area and the same amount of heat conductivity as the full-scale multicylinder engine or the test results are going to be wrong. In the imitation of the test of a real engine, one cannot depart far from the commercial engine itself or the test will not be worth anything.

We hear quite a bit about octane these days, but the single octane value we talk about does not define the gasoline at all. It is handy for us and handy for the public to say 86 octane for housebrand or 92 premium grade. Actually, however, as far as the engine is concerned, it has not defined that gasoline at all. The octane value of a gasoline varies with engine speed as well as with engine design. Some of the gasolines may have a high anti-knock value at low rotative speed of the engine, or the reverse may be true. Obviously, for the cars that are on the road, the gasoline should suit the engine; the engine demand and the gasoline octane value ought to match. We test for that by the road octane test. A car is equipped with a variation of ignition that can be read instantaneously when riding, and it takes quite a little instrumentation for that. The fuel is road-tested for knock at 10 up to 70 miles per hour.

You must get police permission to drive 70 miles per hour because the risk of accident is very high on many of our roads. In winter or in rainy weather the test cannot be carried out at all. So we built dynamometers to do the same thing indoors. We just drive the car on the dynamometer and the car itself drives the fan. That will give you the windage loadings which are cube of speed. It has fly-



Cradle Type Bearing Dynamometer

wheels that can be clutched in and out to represent the weight of the car. This gives the inertia loading. It has an electric dynamometer so we can get hill-climbing effects or downgrades. We can run tests a full eight hours a day regardless of the weather and in addition we can, if we want, either refrigerate the room or heat it. Winter gasolines should be tested in the summertime so as to be ready for next winter, but we don't have the temperatures without artificial means. The reverse is true in the winter—spring and summer gasolines should be tested in the winter. I think the first dynamometer that was built has cost us about $76,000 to get it to the present stage of development. The second one cost about $50,000. These instruments are getting pretty expensive to justify in any research program, because we now have two of them and are getting ready to build a third since we have so much business for them. Our case is that of all the other big oil companies, too. But the beauty of this indoor dynamometer is that after you have run it and you want to calibrate, you just take the car off the dynamometer and make a road test with it.

Another rather interesting tool came up which is also based on the Solex gage idea. Some years ago during the war, Wright asked us to invent a device for measuring piston ring wall pressure. There had been three or four of these developed up to that time, all of which were what we might call single-point machines; take a reading at one place in the ring and hope it was right, then move over to another place, and it took about an hour to read the

Continued on page 1288

Speed Control *and* Synchronization *of* Multi-unit Internal Combustion Engine Plants

By HOMER C. GIVENS, Superintendent, LaGloria Corp., Falfurrias, Texas

PROBABLY many of you are wondering what kind of plants can advantageously use speed control or synchronization or both. To name a few multi-unit examples, there are airplanes, air or gas compressors, electric generating plants, boats and pumping stations.

No doubt the majority of you here today, like myself, have had little to do with the control of airplanes and boats. For that reason, they will be omitted in this discussion.

Now we will get to the reasons for synchronization and speed control. Any time two or more engines run in parallel, synchronization is needed to get maximum efficiency from each unit. When some condition such as suction pressure, discharge pressure, or flow, varies at irregular time intervals at a compressor plant or pumping station, speed control is quite essential, as it is to control frequency in an electric generating plant.

Fig. 1 shows a simple speed control system used extensively in gas compressor plants. Suppose that these compressors are operating in parallel in a casinghead gasoline plant. Here a reducing regulator is installed in the suction line to give a constant suction pressure to the compressor cylinders. The pressure upstream of this regulator, called the field pressure, controls the speed of the engines.

The field pressure is measured by a suitable pressure control instrument which actuates the diaphragm motors, equipped with valve positioners, that set the engine governors for the required speed. This system may also be used to hold a constant discharge pressure with varying demands of output. To do this, the pressure control instrument is connected to the discharge header instead of the suction or field pressure.

Like all control systems, this one has advantages, disadvantages, and limitations. Some of the advantages are that it is simple, low in cost, and needs no special equipment. The limitations are the limitations of the maximum and minimum speed of the engines.

The disadvantages will require more of an explanation than just naming. First, you all know it is difficult to keep a number of diaphragm motors traveling exactly the same distance, with a common actuating pressure. This is especially true with valve positioners that are subjected to vibration, as they are when mounted on the engines.

The second disadvantage of consequence is the changes in the engines. This is caused by uneven wear in the governors and push rods operating the fuel injection valves. These two items probably cause most of the differences in speed of the engines. I have observed differences as great as 20 rpm. in engines in two separate plants. This disadvantage is more pronounced when operating two-cycle engines than four-cycle ones, and the majority of gas compressors are now two-cycle engine driven.

We will now look at some of the methods of individual engine speed control in a multi-unit station. Probably the simplest method is to put a pneumatically set flow controller with automatic reset on the discharge from each compressor or pump. The pressure control instrument output sets all the flow controllers, and they in turn control the individual engines to which they are connected.

This system operates satisfactorily if precautions are taken to eliminate pulsation in the flowmeters on the discharge of the compressors or pumps. The greatest objection to it is the high cost of equipment and installation.

Presented at fifth symposium on "Instrumentation for the Process Industries," Texas A&M College, College Station, Texas, Oct. 11-13, 1950.

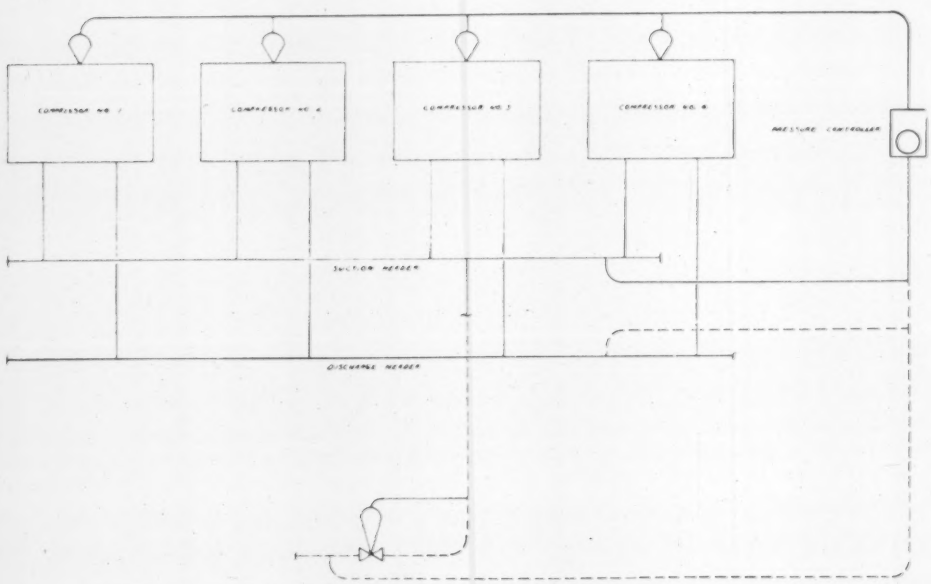


Fig. 1. Typical installation, compressor speed control.

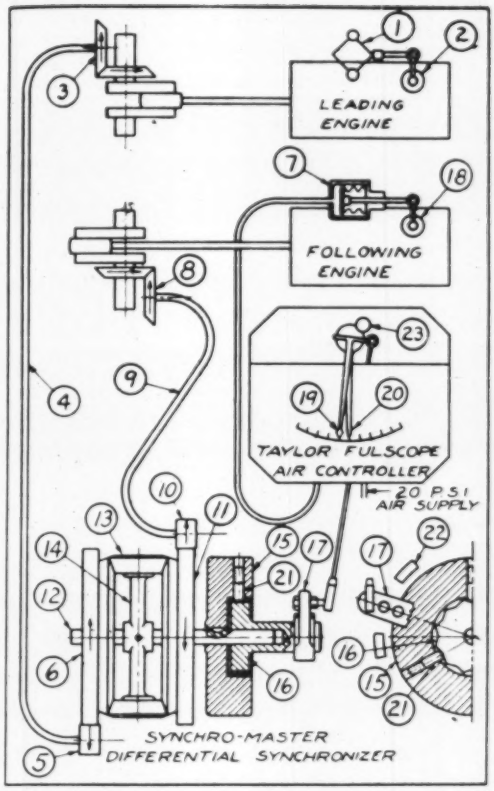


Fig. 2.

Fig. 2 shows a system developed by the Synchro-Master Co. of Seneca Falls, N. Y. This system also keeps the engines phase controlled. "Phase control" is keeping the engine crankshafts in the same angular relation to each other at all times. The advantage of this is to reduce pulsation when several compressor or pump cylinders are operating in parallel.

In Fig. 2 we see two single-cylinder engines, one of which is the reference or leading engine and the other the following engine. As can readily be seen, they are operating 180 degrees apart as to crankshaft angularity.

In this case the governor 1 of the leading engine may be set by hand or some automatic device for the desired speed. Through bevel gears 3, and a flexible shaft, gears 5 and 6 on the leading side of a differential unit, are driven. Gears 8 on the following engine drive gears 10 and 11 on the other side of the differential unit.

When both engines are running at the same speed, gears 6 and 11 are at the same speed and in opposite directions; therefore, gears 13 rotate on a spindle 14 which stays in the same position. However, if one engine changes speed, the corresponding gear in the differential unit changes speed and spindle 14 will start to rotate about its axis and turn shaft 12 which, through clutch 15, operates the pneumatic controller. The controller in turn resets the governor or throttle of the following engine to get it into synchronization with the leading engine. If the controller is equipped with automatic reset, the phase will also be controlled.

When more than two engines are operating in parallel, it is not good practice to use one as a reference. In this case, this same company used a system as shown in Figs. 3, 4, 5 and 6. Here a synchronous motor driving a master line shaft through a variable speed reducer gives the reference speed. The speed reducer may be changed manually or automatically from a controller. The leading side of the differential for each engine is driven from the line shaft and the following side by a flexible shaft or Selsyn slave from the engine.

The Foxboro Company has a pneumatic speed transmitter which has a rotating circular magnet in a metal cup. The cup is supported by cross flexures which determine the amount the cup can rotate. The rotation of this cup actuates a force-balance pneumatic transmitter. A 3-to-15 psi. receiver-controller receives the output of the transmitter and records and controls the speed of the engine.

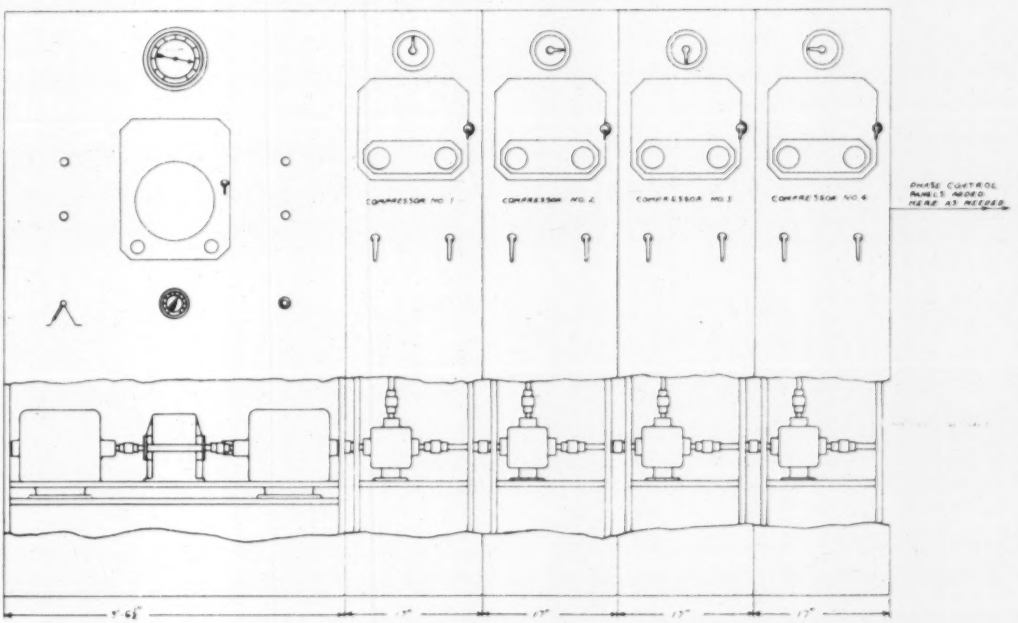


Fig. 3. Panel assembly—Phase control.

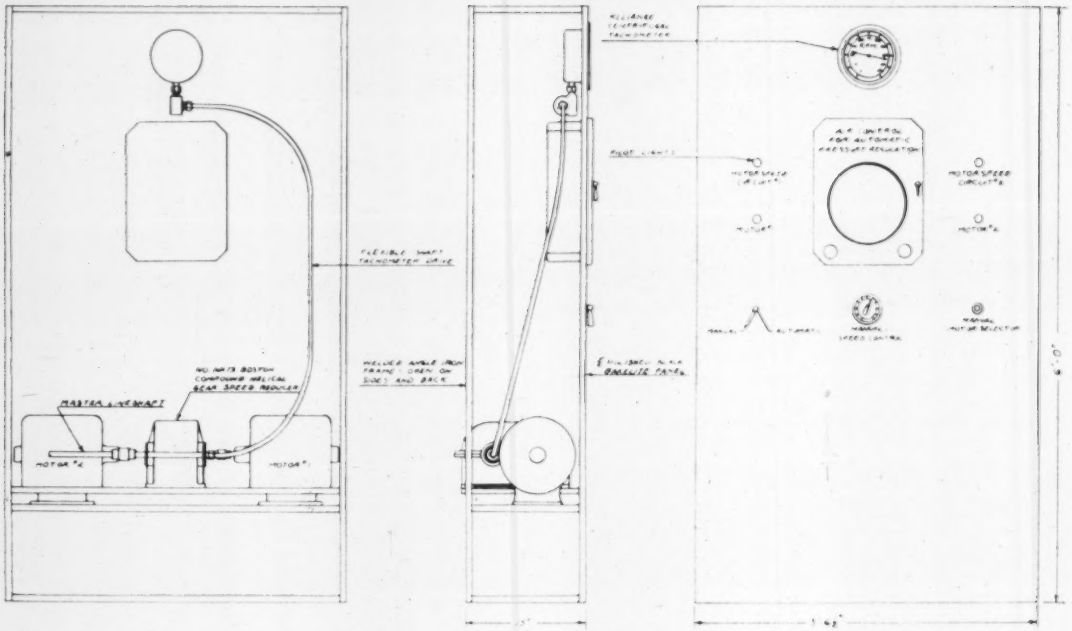


Fig. 4. Master speed control assembly—Phase control.

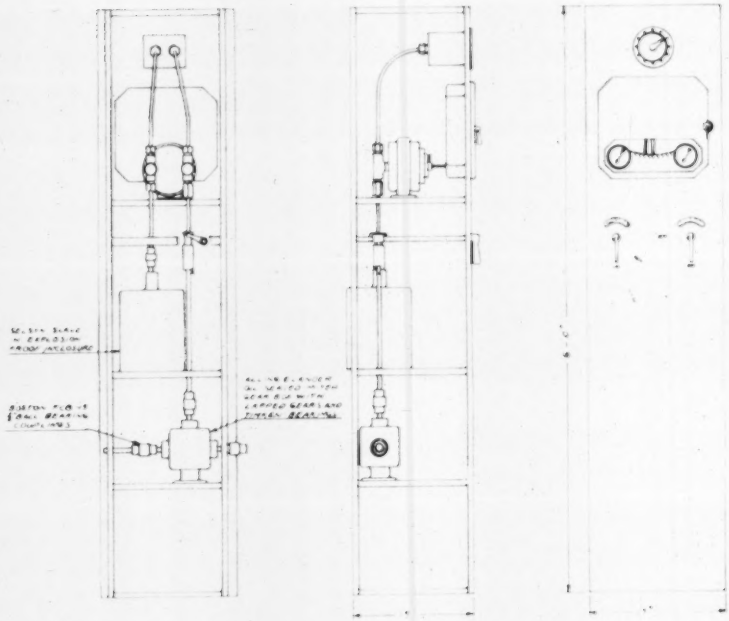


Fig. 5. Phase control panel assembly—Phase control.

The controller in this Foxboro system may be pneumatically set by a master controller and thus all engines of a station could be synchronized.

Taylor Instrument Companies also have a pneumatic speed transmitter that uses a small flyball governor mechanism to operate the force-balance 3-to-15 psi. transmitter. The remainder of the Taylor system is similar to the Foxboro system.

Brown, Bristol, Leeds & Northup, Weston, and several other companies can build a system of speed control from their standard electric tachometer units and pneumatic controllers.

While the writer has not had actual operating experience with these individual engine control systems, contacts made with operators of a Synchro-Master, a Foxboro, and a Taylor system, have indicated favorable operating service for long periods of time with very little maintenance.

The cost of all these systems is high, but not exceedingly so, comparatively, when a large compressor plant or pumping station is being constructed. However, the expense may become a major factor in discussion with the management upon installing one of these systems in an existing plant. At the present time the cost of these systems is between $600 and $1000 per engine.

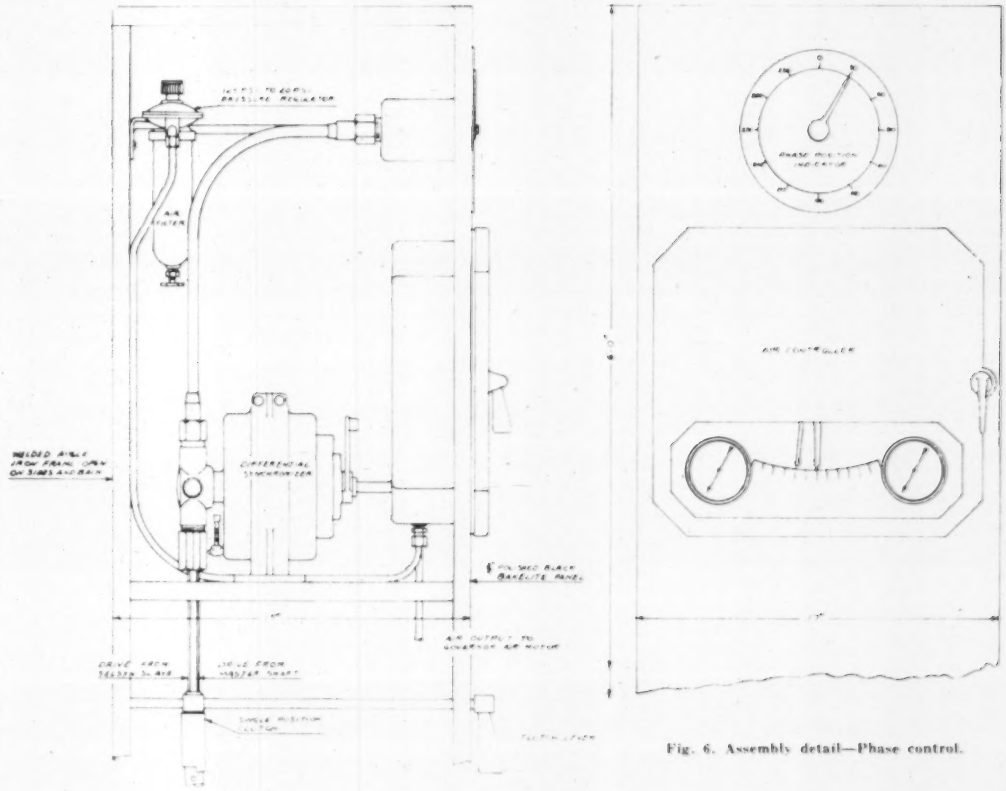


Fig. 6. Assembly detail—Phase control.

It was hoped that by the time this paper was to be given, a control system worked out by the instrument men of the writer's company would have been in operation. However, owing to plant expansion, vacations, and other factors promoting delay, it is impossible to give a working knowledge discussion of it at this time.

Referring to Fig. 1, a variable-frequency power oscillator will be set by the pressure controller. The power from the oscillator will drive a clock motor (terminal shaft speed 1 to 5 rpm. at 60 cycles) connected to a differential mechanism, as in Fig. 7. The speed reducer connected to the other side of the differential will be driven by the engine under control. The spider of the differential connected to the control mechanism of a controller will change the engine speed as the variable oscillator changes the clock speed.

It is believed that this system, including master pressure controller, oscillator, diaphragm motor with valve positioner, and differential unit with controller, could be installed on a six-engine station for $300 per engine.

When several a-c. generators are running in parallel, driven by internal combustion engines, they are held in synchronization by the generated current. However, speed control of the entire unit must be practiced if the desired frequency is to be maintained.

Leeds & Northup make a good frequency controller but it is quite expensive, especially for a small plant producing less than 5000 kva.

Telechron Inc. have an extremely accurate spring-driven pendulum clock which has a hand on the axis of the spider of a differential unit. One side of the differential is driven by the second hand drive of the clock and the other by a clock motor with terminal shaft speed of one rpm. at desired frequency. When the hand is not moving, the frequency is correct. If the load is fairly constant an acceptable frequency may be maintained by manual control. This clock costs about $150.

The system worked out by the instrument men of the writer's company for speed control may be modified slightly and used as a frequency controller. Instead of the variable oscillator, a tuning-fork-controlled oscillator of desired frequency is used and it will drive one motor of the differential unit (Fig. 7). Another motor will be connected to the light circuit and substituted for the speed reducer on the differential unit. The movement of the spider will control the speed of the engines either electrically or pneumatically, thus effecting frequency control.

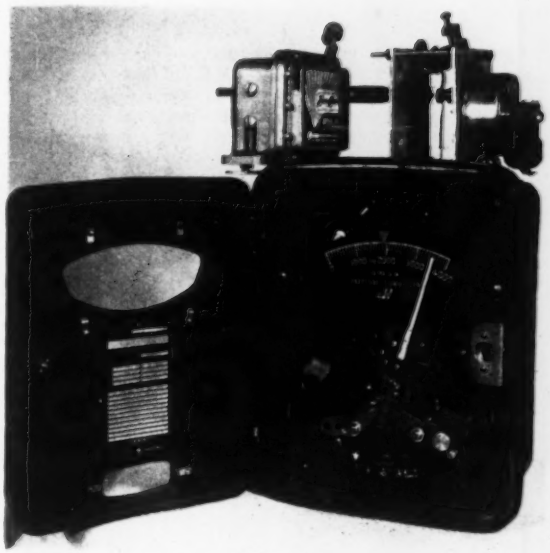


Fig. 7

In conclusion, we may say that speed control is quite important, but the system used depends on what the station economics will allow.

A New Concept of Automatic Control

By R. E. CLARRIDGE, Taylor Instrument Companies, Rochester, New York

I. Introduction

FOR quite some time it has been apparent that although a great deal of work has been done on automatic controllers and control systems, they do not fully meet all requirements of industrial processes. In recent years, our thinking has been principally directed toward a reduction of the magnitude and duration of the "offset" resulting from load changes in the process. This is particularly true in the oil and chemical industries where processes require a wide throttling range (low control sensitivity). So many of the applications in these industries are of this character that automatic reset is a standard feature in the controllers and this returns the controlled variable to the desired value following load changes. In recent years, on temperature applications in particular the derivative function has been added to controllers with automatic reset which further reduces the magnitude of the deviation and brings the temperature back to the control point more quickly.

Now, there is another characteristic of automatic control systems which often is of greater importance than the magnitude and duration of the deviation from the control point after a load change. This is the overpeaking which occurs when a control system is started up or when the controlled variable deviates beyond the edge of the control band. While we normally think of this start-up characteristic as being important only on batch operations, it can be equally important on continuous and semi-continuous operations. It is well established that batch operations are those in which a material is loaded into a vessel such as a kettle and is subsequently "processed" by being brought to a given temperature or pressure. Typical of these batch operations would be the synthetic rubber reactor, the rayon shredder, and canners' retort. Now, the distinction between continuous and semi-continuous processes is not so clear cut. Since all things must start and all things must end, there is no truly continuous process. Sometimes a continuous process is considered one which operates for a day without shut-down. Certainly, most processes which operate for a week, or a month, or a year without shut-down are classed as continuous. For our convenience, we will define our semi-continuous processes as those continuous processes which must be shut down for various purposes more frequently than once per day. Typical of these semi-continuous processes are milk and juice heaters. Now, on these batch and semi-continuous processes an overpeak on start-up is often more serious than the "offset" due to load changes and, as might be expected, quite a bit of work has been done in this field.

As a matter of fact, it was in the field of batch processing that derivative action was first used on a widespread scale. It was found that a proportional controller with derivative action improved the start-up characteristics of a controller on a process in two ways.

(1) It reduced the rounding-in of the temperature or other controlled variable at the start-up and still prevented overpeaking.

(2) It permitted narrowing the throttling band or increasing the control sensitivity of the controller so that the offset which occurred due to subsequent load changes was considerably reduced.

Now, there are many batch and semi-continuous applications where both the derivative function and the automatic reset function should be used for best results. The purpose of the derivative feature would be to prevent overpeaking and narrow the throttling range, while that of the automatic reset feature would be to correct for load changes which subsequently occur in the process. Now unfortunately, when automatic reset and derivative functions are incorporated in a controller in the conventional manner, the derivative function reduces but does not eliminate the overpeaking. It cannot do this because control action is not initiated until the controlled variable reaches the control point. In other words, the automatic reset feature shifts the control band in such a direction that it is always on the most unfavorable side of the control point during the start-up condition. Therefore, when automatic reset is added to a controller with proportional and derivative action in the conventional manner, the controller which has performed satisfactorily from the start-up viewpoint will now perform unsatisfactorily.

Therefore, on each batch and semi-continuous process, we have been faced with a compromise. If a good start-up characteristic is most important, automatic reset cannot be used and the resulting "offset" due to load changes must be tolerated. On the other hand, if automatic reset must be used to compensate for load changes, a poor start-up characteristic must be accepted or the equipment must be started up manually. Although manual start-up may not be too objectionable on processes which operate for a day, a week, or a month, it is not very attractive on jobs which start up more frequently. Therefore, in the use of automatic controllers, we have come to accept the following statements as axioms:

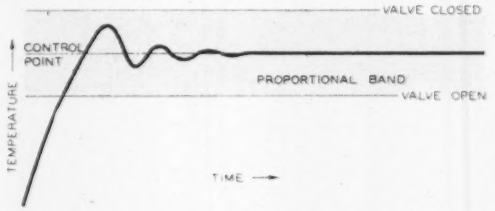


FIG. 1A

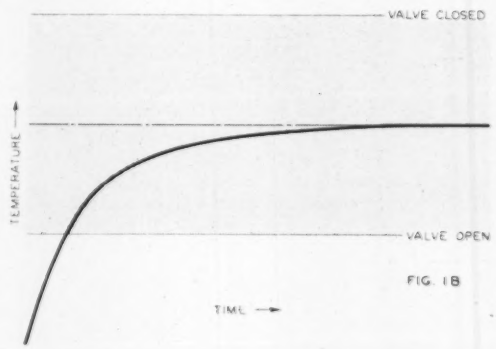


FIG. 1B

(1) On critical control problems with load changes where excess deviation of the variable is important, automatic reset must be used and the process must be started up manually.

(2) On critical control problems which must be started up automatically and overpeaking of the controlled variable must be avoided, automatic reset can be used and subsequent load changes must be handled manually.

Now, the purpose of this paper is to outline an improved control system which incorporates three control effects in such a way that automatic reset can be used and still overspeaking on start-up avoided.

Although the undesirable overpeaking characteristic has been selected as the best method of illustrating the improved performance of this new control system, there are many discontinuities in continuous processing which are equally difficult to handle. Typical of these are the excursion of the controlled variable beyond the control band for extended periods due to "no load" or "excess load" and the manual shifting of the set pointer.

*Presented at the fifth symposium on "Instrumentation for the Process Industries," Texas A & M College, College Station, Texas, Oct. 11-13, 1950.

II. The Start-Up Problem

First, let us briefly review the start-up characteristics of the conventional control systems and set down a few equations which illustrate their performance. Assume that all of the controllers are applied to a single process which involves the heating of a material to a predetermined temperature and holding it at that temperature. Assume that the heat input to the process is proportional to the valve opening. Since we must select a given load for comparison purposes, let us select the 50 percent load condition which requires that the valve remain half open to maintain the temperature at the control point.

A. The Proportional Controller

When a proportional controller is adjusted to a reasonably narrow proportional band to minimize the effect of load changes, the temperature record on the start-up might be very similar to that shown in Fig. 1A. Note that the shaded

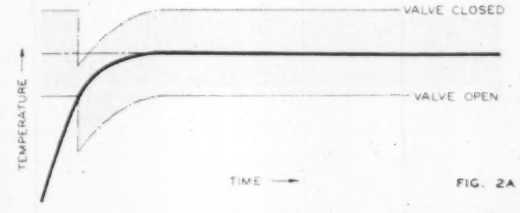


FIG. 2A

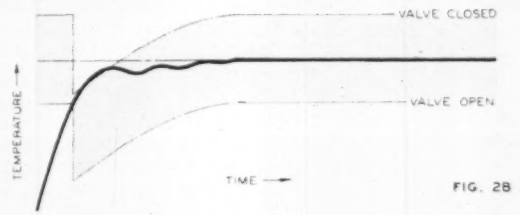


FIG. 2B

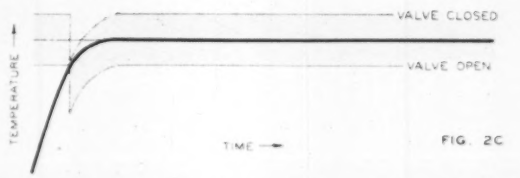


FIG. 2C

area extends from the temperature corresponding to the open valve position to that of the closed valve position. In this and in subsequent figures, the position of the temperature in the band at any time, therefore, indicates the opening of the valve. Now, in Fig. 1A it will be noted that overpeaking occurs and, if this must be avoided, the proportional band can be widened as illustrated in Fig. 1B. Although this eliminates the overpeaking, this adjustment of the controller is often unsatisfactory because it takes the temperature too long to come in to the control point, and also because the deviation following subsequent load changes will be excessive. For the record the equation most often used to express the action of a controller of this sort is

(1) $$p - P_c = S(x - x_c)$$

$$\text{or} \quad \frac{dp}{dt} = S\frac{dx}{dt}$$

Change in output pressure of the controller

$$(p - p_c) \text{ or } \frac{dp}{dt}$$

Change in the input to the controller, change in the controller variable.

$$(x - x_c) \text{ or } \frac{dx}{dt}$$

S is the constant relating the output to the input of the controller.

B. The Proportional plus Derivative Controller

Now, if the derivative is added to the proportional response in the controller, the start-up characteristics can be materially improved. The derivative function has a stabilizing effect and with a given band width, it reduces the tendency of the controller to oscillate. For example, in Fig. 2A the band width remains identical with that in Fig. 1A but sufficient derivative action has been added to prevent overpeaking. If we continue to use the proportional band as a means of illustrating the valve position, it shifts downward at the time the temperature reaches the lower edge of the band. Fig. 2B illustrates the characteristic approach curve which may be obtained when the derivative function is excessive. When a curve similar to that illustrated in Fig. 2B is obtained, the proportional band may sometimes be narrowed as shown in Fig. 2C so that the temperature arrives at the control point more quickly than would be the case if the proportional response were left in

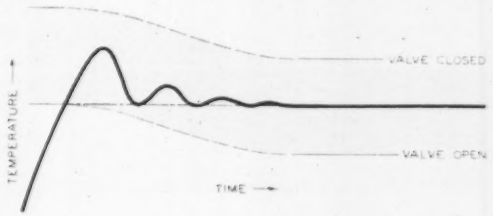


FIG. 3

the adjustment corresponding to that shown in Fig. 2A. In this particular connection it must be pointed out that the figures are illustrative rather than actual, for there are very few applications on which the approach curve is as perfect as shown in Fig. 2C. Again, for the record, the equation most often used to express this performance is

(2) $$p - p_c = S(x - x_c) + ST\frac{dx}{dt}$$

$$\text{or} \quad \frac{dp}{dt} = S\frac{dx}{dt} + ST\frac{d^2x}{dt^2}$$

$$(p - p_c) \text{ or } \frac{dp}{dt}$$

is the change in output pressure of the controller.

$$(x - x_c) \text{ or } \frac{dx}{dt}$$

is the change in the input to the controller, the change in the controlled variable.

S, T are constants relating the output to the input of the controller, the controller adjustments.

C. The Proportional plus Reset Controller

Now when automatic reset is added to the proportional response in the controller and the controller is in a satisfactory adjustment, the start-up characteristic may be very similar to that illustrated in Fig. 3. Note that the proportional band is entirely above the control point during the start-up period and that it subsequently shifts downward after the temperature passes this control point. Owing to the fact that there is no action until the control point is reached, the overpeaking is considerably worse than it was before the automatic reset feature was added. If the instrument sensitivity were lowered or its proportional band widened as was done in Fig. 1B, the overpeaking will become worse rather than better. This is due to the fact that the band becomes wider on the upper side of the control point and, therefore the rising temperature will make a greater excursion into this band before the shift of the band returns the variable to the control point. To date, there has been no satisfactory method suggested for elim-

inating this overpeaking when the proportional and automatic reset responses alone are used.

For the record, the equation for this controller is

$$\frac{dp}{dt} = SR(x - x_o) + S\frac{dx}{dt} \quad (3)$$

dp/dt is the rate of change of output pressure of the controller.

$(x - x_o)$ is the change in the controlled variable.

dx/dt is the rate of change of the controlled variable.

S, R are constants determining the magnitude of the control effects, the controller adjustments.

D. The Conventional Controller with Three Responses

Now, when the proportional, derivative, and automatic reset functions are incorporated in one controller in the conventional fashion, the start-up characteristic may be very similar to that illustrated in Fig. 4A. Note that the automatic reset function still dominates the proportional band and places it above the control point during the start-up

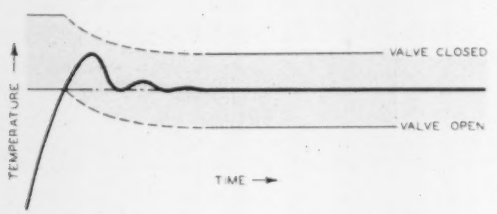


FIG. 4A

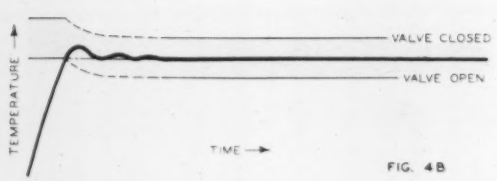


FIG. 4B

period. Since the derivative function does not begin to act until the control point is reached, overpeaking is reduced but cannot be avoided. As is frequently the case when the derivative is used, the proportional band can be narrowed and a further reduction in overpeaking may be accomplished as shown in Fig. 4B.

The equation most often used to describe mathematically the performance shown in Fig. 4A and B is

$$\frac{dp}{dt} = \overline{SR}\,(x - x_o) + \overline{S}\frac{dx}{dt} + \overline{ST}\frac{d^2x}{dt^2} \quad (4)$$

$$= S\left[R\,(x - x_o) + \frac{dx}{dt} + T\frac{d^2x}{dt^2}\right]$$

It will be noted that this equation is obtained by adding the responses. Unfortunately, the mechanisms which have been used in conventional control systems do not produce results which correspond to this equation.

To illustrate this, let us look at Fig. 5 which is a schematic diagram of the circuit used in some of our conventional controllers. As the temperature increases, the Bourdon tube moves the baffle toward the nozzle, increasing the back pressure and actuating the relay valve. Since the relay is reverse-acting, the output pressure diminishes. If the reset restriction R is closed (R = 0) and the derivative restriction T is open (T = 0), the falling output pressure on the right side of the bellows moves the nozzle to the right, thereby causing the nozzle to move along with the baffle. Now, if for a given pressure change on the right side of the bellows, the nozzle movement is large owing to the sensitivity adjustment S, the instrument sensitivity is low and

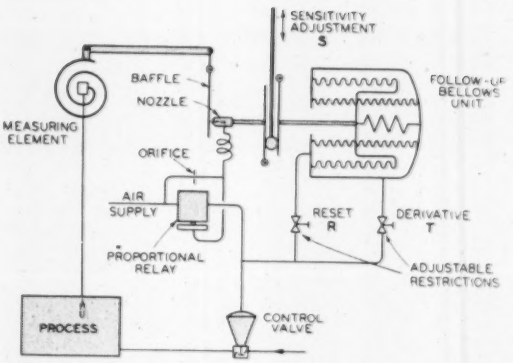


FIG. 5

its throttling band is wide. On the other hand, if the nozzle motion for the pressure change is reduced by the sensitivity adjustment S, the controller sensitivity is high and the throttling band is narrow. The automatic reset feature is added by opening the reset restriction R so that, over a period of time, this pneumatic sensitivity reduction is canceled. In other words, the pressure changes on the right side of the bellows are canceled by corresponding pressure changes on the left side of the bellows so that the nozzle is restored to its original position and the temperature is restored to the control point. As the derivative restriction T is gradually closed, the pressure to the control valve must lead the pressure on the right side of the bellows by an amount depending upon the restriction. A study of the circuit will show that the magnitude of the lead is dependent upon the rate of change of the controlled variable, but the lead time is primarily a function of the restriction T.

Now, let us consider the adjustments of this controller S, R and T. First, set R equal to infinity (open the restriction) and T equal to zero (open the restriction). While the output pressure enters both sides of the bellows unit, the nozzle does not move and the controller has a high sensitivity. Now, when R and T are closed equal amounts (the product of RT equals 1), and again the nozzle does not move and the controller remains in a high sensitivity. Now although we know this to be the fact from this analysis of the circuit as well as from actual observation, this is not indicated by equation (4). Therefore, equation (4) must not apply to this particular controller. Although it is not our intention to go through the mathematical details, the equation which describes the action of the controller of Fig. 5 with a reasonable accuracy is

$$\frac{dp}{dt} = \frac{(1+RT)}{(1-RT)}S\left[\frac{R}{1+RT}(x - x_o) + \frac{dx}{dt} + \frac{T}{1+RT}\frac{d^2x}{dt^2}\right] \quad (5)$$

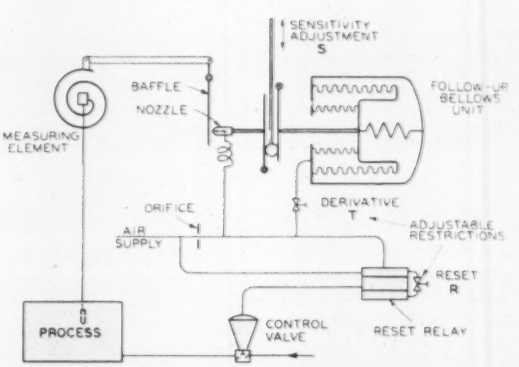


FIG. 6

Now let us examine this equation to determine how well it fits the observed results. First, when we set T = 0, the equation becomes identical with equation (3). In other words, the instrument behaves in an orthodox manner with the proportional and automatic reset responses. When the reset restriction R is closed (R = 0) equation (5) becomes equation (2), and again the instrument behaves in an expected fashion. Now let us set the product of RT = 1 and [(1 + RT)/(1-RT)] becomes infinite, indicating that the sensitivity of the controller is extremely high. This corresponds with the observed results. Therefore, although we have not proved that equation (5) is a good mathematical description of the controller shown in Fig. 5, it appears to correspond with the observed results and this can be verified mathematically.

Now, let us take a look at the controller to determine whether its responses can be rearranged to produce more satisfactory results than illustrated in Fig. 4. First, if we are to prevent overpeaking, it is essential that the proportional band must not shift above the control point during the start-up period as illustrated in Figures 3 and 4. Since

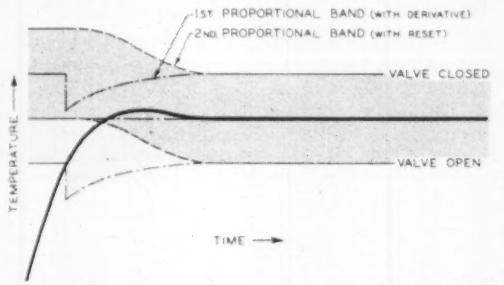


FIG. 7A

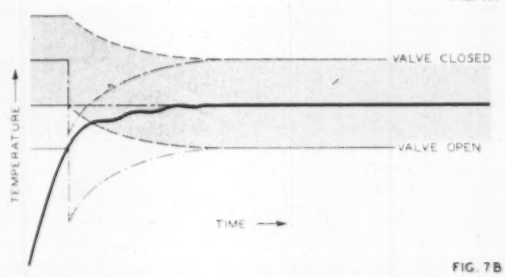


FIG. 7B

this shifting of the band occurs each time that automatic reset is used in the circuit, let us separate the circuit and in the first half put only the proportional and the derivative responses. Since automatic reset is always necessary to prevent the "offset" due to load change, let us incorporate it in the second half of the circuit so that it will not disturb the proportional band of the first half. Of course, if the derivative and proportional responses are to be passed on to the diaphragm valve, the second half of the circuit must also have a proportional response. In short, we are suggesting a controller divided into two sections. The first incorporates proportional and derivative responses, and the second incorporates proportional and automatic reset responses. Since two proportional bands exist, this controller could be called a two-band controller, the first band being affected by the derivative response and the second being affected by the automatic reset response.

Now, let us look at Fig. 6 which illustrates a method of obtaining these results. Again, an increasing temperature in the process moves the baffle toward the nozzle. The increased nozzle back pressure in this case is connected directly to the left side of the bellows, causing the nozzle to back away as the baffle approaches. By varying the mechanical linkage between the motion of the bellows and the nozzle, the sensitivity or proportional band of the controller can be adjusted. If a restriction is incorporated in the line leading to the bellows, the derivative function is added to this section of the controller in the customary fashion. If the output of the controller is fed to a relay which incorporates the proportional and automatic reset responses, the automatic reset feature can be added without shifting the band in the first portion of the circuit.

Now, let us examine the start-up characteristics of a controller of this type. Refer to Fig. 7A. During the start-up period, before the temperature reaches the bottom edge of the first proportional band, this band is divided by the control point. Since the derivative function is incorporated in this portion of the control circuit, the band shifts downward as soon as the temperature reaches its lower edge as illustrated in Fig. 2. The position of the temperature within this band at any time is indicative of the output pressure of this half of the control system and it will be seen that very shortly after the temperature enters the control band the output pressure is more than 50 percent of the way to its other extreme position. Since the output pressure from this portion of the control circuit is now connected to a relay incorporating the reset function, this relay is actuated as soon as the pressure reaches a given value, and the second control band begins to shift downward from its unfavorable position. In other words, in the eyes of the reset relay, the temperature has apparently reached the control point at the time the output from the first half of the controller reaches the actuating value. Owing to the

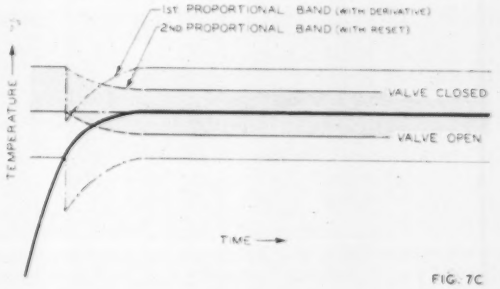


FIG. 7C

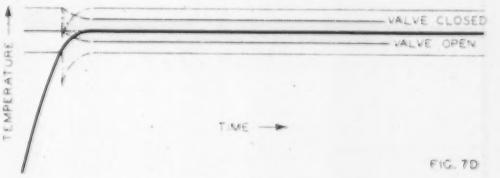


FIG. 7D

derivative action, it is possible to make this output pressure reach the actuating value long before the rising temperature reaches the actual control point. In this interval the controller can, if properly adjusted, shift the second proportional band downward so that overpeaking is prevented. Actually, in Fig. 7A the derivative response was not great enough to shift the second proportional band rapidly enough to prevent overpeaking. In Fig. 7B the derivative response has been increased, the second proportional band shifts more quickly, and overpeaking is prevented.

As was the case in Fig. 2B, when results like that shown in Fig. 7B are obtained, it is often possible to increase the proportional response or narrow the proportional band and obtain better characteristics. This can be accomplished in the normal way by increasing the sensitivity in the first portion of the circuit or it can be done in the reset relay. In Fig. 7C the proportional band of the reset relay is indicated as a half of its previous width. Note that it is still located during the start-up period on the unfavorable side of the control point. While the reset relay illustrated in Figs. 7A and 7B can be considered to have a gain of 1, the reset relay illustrated in Figs. 7C and 7D has a gain of 2. In Fig. 7D the sensitivity of the controller has been further increased and an ideal start-up characteristic is illustrated.

Now this is all very well—the experienced instrument man might say—but how do I know that when the instrument is properly adjusted to prevent overpeaking it will respond in a satisfactory manner to load changes without excessive deviations from the control point when load changes occur? One would think that on difficult applications the throttling range or proportional band would have

Continued on page 1290

Unbalanced Force Reactions *in* Control Valve Plugs *and their* Influence *on* Diaphragm-motor Design *and* Operation

By RALPH A. ROCKWELL, Director of Engineering, Mason-Neilan Regulator Co., Boston, Mass.

Introduction

THIS report on the net unbalanced force reactions in single- and double-seated valves is a summary from a series of tests and studies. The work has extended over a period of eight years. In some instances the main test objective was to study some other characteristics such as rotational stem forces, valve capacity, flow characteristics; or cavitation, etc., along with net stem force reactions. The material will be restricted in scope to present the subject in simplified perspective, allowing a more interesting discussion of the practical problem of control valve usage. Comparisons of forces with different type plugs will be made, with particular emphasis not only on the magnitude of the forces, but the force direction and its rate of change.

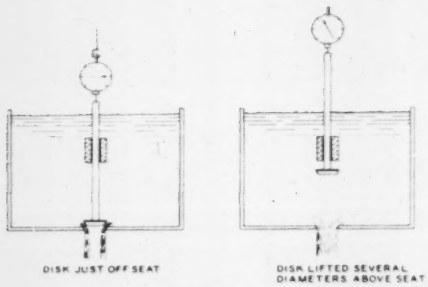


Fig. 1. Valved Tank with Disk.

The particular problem is the application of present-day knowledge about the behavior of control valve plugs under relatively high pressure drops to the selection of diaphragm motors. Special emphasis will be given to the behavior of conventional diaphragm motors and springless motors as applied to both single- and double-seated valves.

Although there are a good many things to be learned about the forces acting on valve plugs under high pressure drop, there are certain properties which can be examined qualitatively and quantitatively to give aim and purpose to the discussion.

For many years there has been a tendency toward oversimplification in analyzing the forces acting on valve plugs throttling flows at high pressure drop. Double-seated valve plugs, for example, are loosely called "balanced." The only unbalance is generally considered to be the difference in seat areas. In single-seated designs the only force generally considered is that occurring with the valve closed or nearly closed. This force is simply the seat area times the differential pressure across the valve.

Although it is true that the double-seated construction greatly reduces the net stem force, many valve plug designs in actual service are far from balanced. The force reactions for single-seated valves are also relatively complex. Fortunately, a simple analysis can be made which clearly sets forth the important point to be considered in the understanding of the force reactions.

First, consider the forces acting on a single-seated valve plug. Such a unit in the simplest form is shown in Fig. 1. The round disk operates to open and close a circular orifice in the bottom of a tank of constant head and unlimited supply. With the disk close to the seat, the force exerted on the plug, due to the pressure of the water is substantially the disk area times the net head. As the plug is withdrawn from the orifice, this force diminishes and, in the second sketch with the disk several diameters out of the orifice, the net force acting on the valve plug due to the fluid passing through the orifice is reduced to zero. This is an experience familiar to anyone operating the stopper in a bath tub, and it represents the key to the whole problem of valve stem forces. The problem lies not in consideration of the force acting on the valve plug near the closed position, but in the *change* in force throughout the stroke. In practical valve plug design, the change in force throughout the stroke varies with the design of both the plug and valve body. If the plug is lifted to the point where the flow is a substantial portion of the maximum potential flow, the change in force will be a substantial portion of that existing near the closed position. This force change must be taken into account in the selection of a suitable motor operator.

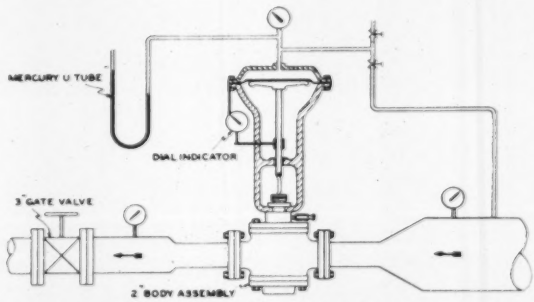


Fig. 2. Original Test Apparatus.

While the force reactions in single seated valves are necessarily complicated, a series of tests conducted on several single-seated valve plugs differing radically in construction makes possible some important generalizations. By treating double-seated valves as a combination of two single-seated valves operating in opposite flow directions, an important analogy is drawn between these two basic types.

Piping Installation and Test Equipment

The first studies of unbalanced forces were made in 1942, and Fig. 2 shows the test set-up. This work was done prior to the time when strain gages were generally available for industrial use. Net comprehensive stem force was measured by fluid pressure on a calibrated diaphragm.

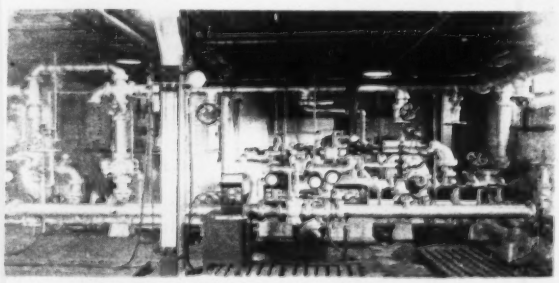


Fig. 3. Test Laboratory.

Presented at fifth symposium on "Instrumentation for the Process Industries," Texas A&M College, College Station, Texas, Oct. 11-13, 1950.

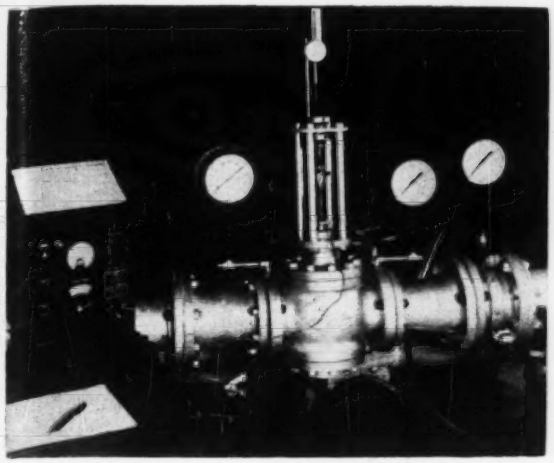


Fig. 4. 4-in. Test Valve and Strain Equipment.

Although crude, this arrangement provided the first quantitative measurements of unbalance force reactions on double-seated valves, and permitted better evaluation of some of the difficulties encountered in field installations. Subsequent more accurate tests substantiated the results obtained to within accepted hydraulic test accuracy.

The major part of the later test work was conducted on water with the test equipment shown in Fig. 3 and 4. A 200-horsepower motor operated two DeLaval centrifugal pumps on the same shaft. The piping was arranged for either parallel or series pumping, providing a head of 160 psi. at 1200 gpm., and 60 psi. at 4000 gpm.

The test manifold for the 4-in. valves was 6 in. with 6 x 4-in. flanged reducers bolted directly to the valve. Six-inch gate valves installed upstream and downstream provided a means of adjusting both the static pressure and pressure drop across the test valve.

A scale layout for this manfold is shown in Fig. 5. The upstream and downstream pressure taps were taken from the 6-in. run using piezometer rings. The pressure drop across the test manifold was checked by removing the valve and bolting the two flanges of the manifold together. The piping was then tested for pressure loss and corrections applied to the test readings to give accurate pressure measurement existing at the inlet and outlet of the test valve.

Flows were measured by a series of interchangeable calibrated open-discharge flow nozzles, and the inlet nozzle pressure head by a well type mercury manometer. Test pressure gages were used for static pressures above 30 psi. and a mercury manometer for static pressure and pressure differential below 30 psi.

During the tests on the 4-in valves it was impossible to maintain constant pressure drop of 100 psi. at all lifts. A series of force readings were made at various lifts and the pressure drop was varied substantially. These readings were plotted to confirm the assumption that the developed force on the plug stem varies directly with the pressure drop through the ranges where this assumption was used. It was felt that this run was sufficient evidence to justify this procedure, and the plotted data have been corrected on this basis. Actual pressure drop generally varied from about 80 to 95 psi.

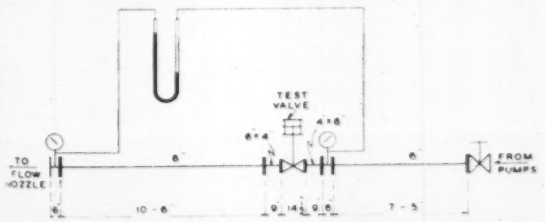


Fig. 5. Piping Layout for 4-in. Test Valve.

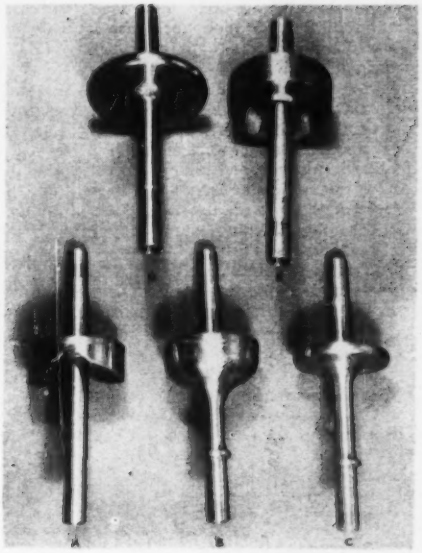


Fig. 6. 4-in. Single-seated Test Plugs.

A fabricated steel superstructure was bolted to the valve bonnet, and the plug lift adjusted by two special lock nuts which held the plug stem in successive positions. Plug lift was measured from the seated position by a dial type micrometer gage.

Net stem compressive and tensile forces were measured by a strain gate unit, which was assembled as a part of the plug stem. The strain element was accurately machined from a piece of steel with a tubular section which gave the required sensitivity. Two SR-4 strain gages were cemented diametrically opposite on the tubular section. This arrangement, with a temperature-compensating gage unit, permitted direct measurement of stem strain in microinches per inch of gage length. The strain gage unit was calibrated in pounds load by a weigh beam before and after the test to check all components of the force measuring system. The force readings are well within plus or minus 5 percent accuracy, which is ample for practical analysis.

Five different types of single-seated plugs were tested in a 4-in. body (Fig. 6). Plug "A" is a percentage V-port with two ports. Plug "B" is a percentage parabolic plug with the same lift and flow coefficient as the V-port. Plug "C" is a quick-opening disk. Plug "D" is a special quick-opening overlapping disk, fabricated to study as an extreme case the force reactions as the disk approached the seat. Plug "E" is a special cup-shaped disk to analyze the force behavior when only the thin edge of the cup is subjected to the fluid velocity.

Fig. 7 shows the 4-in. double-seated valve plugs tested under the same conditions. The plugs shown were primarily made up to test rotational forces and flow characteristics.

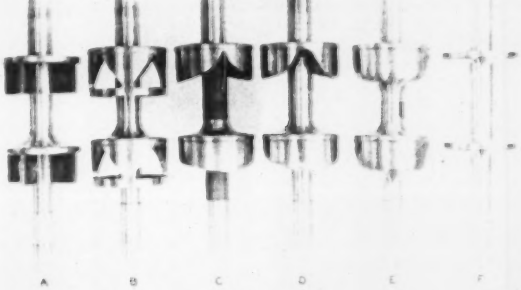


Fig. 7. 4-in. Double-seated Test Plugs.

Vertical stem forces were also measured, and this report will be confined to force measurements on the percentage V-port plug (D), percentage parabolic plug (E), and the quick-opening disk (F).

The single-seated and double-seated body assemblies are shown in section drawing, Fig. 8. All single-seated plugs were first tested with the flow left to right, as indicated by the arrows. In this case, the differential pressure, or fluid velocity, tends to open the valve, and the plug stem is in compression opposing the fluid force. The body was then reversed in the test manifold, and all plugs were again tested with the flow through the body right to left. This flow direction produces forces tending to close the valve and the plug stem is in tension.

All double-seated plugs were tested with the flow through the body in the normal manner, left to right. The parabolic plug was also tested with the flow reversed.

Parabolic Plug Tests

Fig. 9 plots the net stem force in pounds with respect to lift for a 4-in. single-seat percentage parabolic plug with 100 psi. drop across the valve body. Sketch "A" illustrates

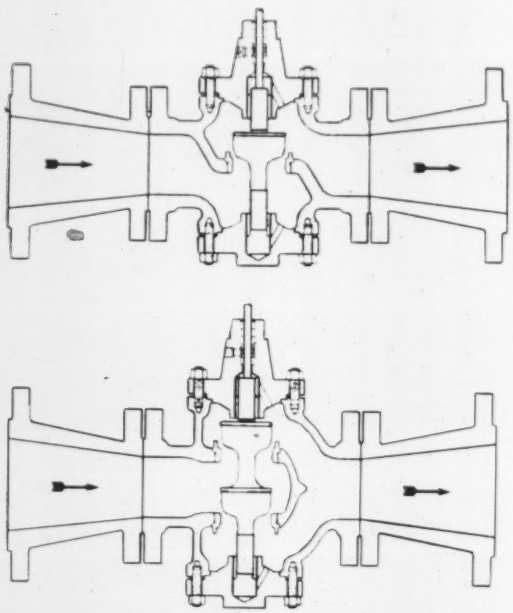


Fig. 8. Cross-section of Single- and Double-seated Valves.

the flow entering under the seat, indicates the plug stem in compression, and identifies the force-lift curve. The net force at the nearly-closed or zero-lift position can be estimated from the seat area of 11 sq. in. and the pressure drop of 100 psi., giving a net upward force of 1100 pounds.

Actual measured stem compression at 0.010 in. lift is slightly in excess of this value. This is within experimental accuracy owing to possible error in force measurement, the difficulty of determining the exact seat area with beveled seat, or the exact differential pressure.

Above 0.20 in. lift the unbalanced force falls off rapidly, and at 0.90 in. lift the rate of change of force reaches a maximum. If it were possible to continue to increase the plug lift, the force would continue to diminish, and would necessarily approach zero. In practical design there is always some residual force at rated lift, since the maximum exposed port areas are restricted to maintain a reasonable drop across the ports with respect to the body drop. Here the maximum force is 1190 lbs. and the minimum is 180 lbs. giving a total change in force of 1010 lbs.

There is no reversal in the direction of the force. Although the magnitude of the force changes with the lift, the force is always in the same direction, tending to open.

Sketch "B," Fig. 9, identifies the force-lift graph when the flow enters over the seat, tending to close. The calcu-

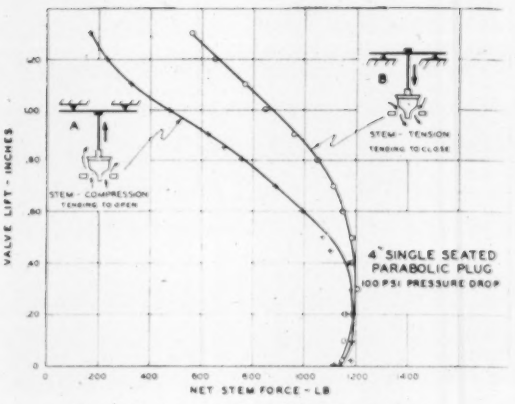

VALVE LIFT - INCHES
NET STEM FORCE - LB
A
STEM - COMPRESSION TENDING TO OPEN
B
STEM - TENSION TENDING TO CLOSE
4" SINGLE SEATED PARABOLIC PLUG
100 PSI PRESSURE DROP

Fig. 9. Single-seated Parabolic—Lift vs. Force.

lated stem tension in pounds with the plug just off the seat equals the area of the seat, minus the area of the stem, multiplied by the pressure differential. Up to about 0.3 in. lift, the force is nearly the same as in "A" since the stem area represents about 1 percent of the seat area. Then the force starts to fall-off, but more slowly than in "A," and at 1.25 in. rated lift the force has dropped to 580 lbs., a net change in force of 620 lbs. Again, note that there is no reversal in direction.

Fig. 10 is a composite graph, showing the lift-force relationships of Fig. 9 and the flow-force relationship for the same test. The ordinate scale is in percent of maximum lift, and also percent of maximum C_V (gpm. at 1 psi. pressure drop). The flow characteristic of the test plug is essentially equal percentage, giving a fairly flat profile to the plug contours in the first portion of the lift. When plotted in terms of flow, this flat portion of the force-lift curve almost disappears, and the force is more nearly proportional to the flow at constant drop.

The important point is that any appreciable flow through the body in opposite directions produces a substantial diffence in the net stem force. At maximum flow, in this example, the difference in stem force amounts to 400 lbs.

Now, since the double-seated plug is really two single-seated plugs with the flow across the ports in opposite directions, this force difference should show up when this type of plug is tested.

The graph (Fig. 11) was developed to predict the force behavior of a double-seated parabolic plug from test data on the single-seated plug. In the double-seated valve the lower plug is usually reduced in diameter so that it just passes through the upper seat ring. Because of this small area difference, a double-seated valve is not completely balanced. The lift-force curve of the lower plug (flow over the seat) has been displaced to a lower force value directly proportional to the reduction in seat area. Notice that these forces are plug, not stem forces. The net stem force

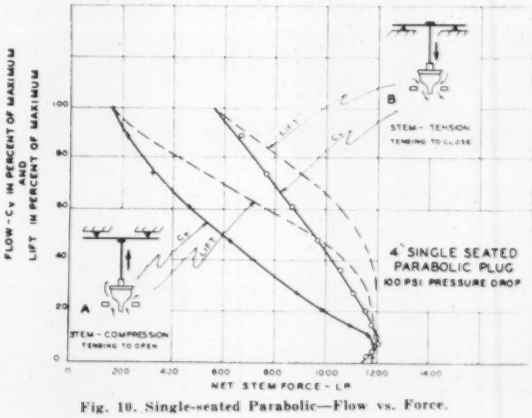

FLOW - Cv IN PERCENT OF MAXIMUM AND LIFT IN PERCENT OF MAXIMUM
NET STEM FORCE - LB
A
STEM - COMPRESSION TENDING TO OPEN
B
STEM - TENSION TENDING TO CLOSE
4" SINGLE SEATED PARABOLIC PLUG
100 PSI PRESSURE DROP

Fig. 10. Single-seated Parabolic—Flow vs. Force.

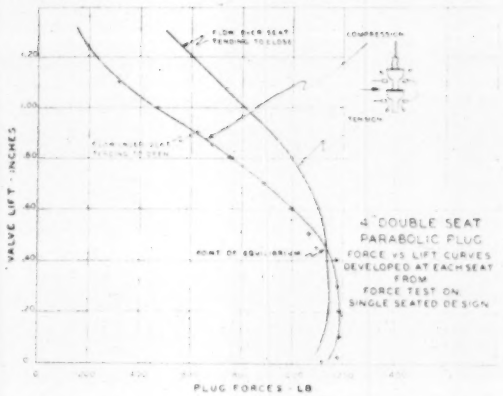


Fig. 11. Double-seated Parabolic—Lift vs. Plug Force, from S.S. Data.

is the difference between the curves. The horizontal distance between the curves can be read on the plug force scale to determine the net force on the stem tending to open or to close. At 0.4 in. lift the two curves intersect and the net force is zero. This is the equilibrium position.

The net force difference between the two curves has been plotted in Fig. 12. This curve developed from the single-seated plug test data, closely duplicates the general character of the tests on the double-seated plug. The maximum unbalance is about 380 lbs., whereas tests on the double-seated valve with comparable seat area gave a maximum unbalance of 480 lbs. This check is as close as should be expected owing to differences in the flow pattern, the body porting, and the assumptions used in developing this graph.

Fig. 13 shows the lift-net stem force relationships of a 4-in. double-seated percentage parabolic plug at 100 psi. pressure drop. Sketch "A" identifies the force-lift curve with the flow entering in the normal manner. In the closed position the net force is a force tending to open which equals the difference in areas between the two seats times the differential pressure. As the plug is lifted, velocity effects on the plug result in forces tending to close the valve. At 0.38 in. lift, the two opposing forces are equal. This point has been identified as the equilibrium point. This phenomenon can be easily observed by passing flow through a double-seated parabolic valve and allowing the plug to move freely into this position. Force must then be applied to the plug stem to either close or open the valve and when the force is removed the plug will return to the equilibrium position. Above 0.38 in. lift the force is always in the closing direction. This force increases rapidly and at full lift is approximately 460 lbs. From extensive test data and from various field service reports on compressible and non-compressible fluids, the general character of this curve of stem force on the parabolic plug has been clearly established. The magnitude of the force developed under conditions of high pressure drop is a serious limitation on the

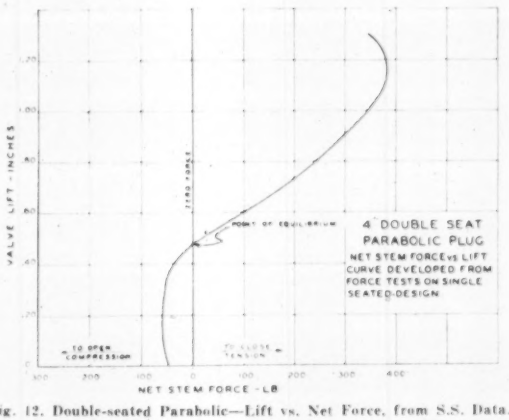


Fig. 12. Double-seated Parabolic—Lift vs. Net Force, from S.S. Data.

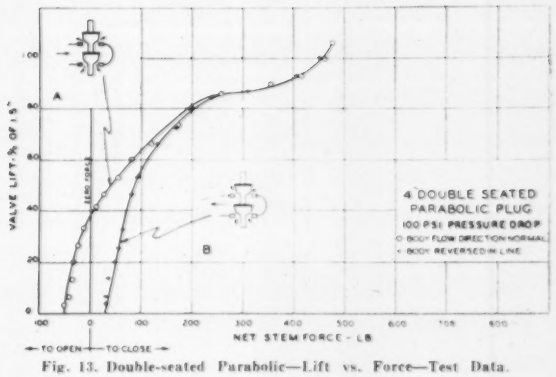


Fig. 13. Double-seated Parabolic—Lift vs. Force—Test Data.

use of this style of plug with conventional pneumatic motor operators.

When the body is reversed in the line (Sketch "B") the net force at the seated position is a force tending to close the valve. At the seated position and at all lifts, the net stem force is now in the same direction. Just above 80 percent of maximum lift, the net stem force is the same whether the flow is brought in between or over the bridge wall.

It is reasonable to assume that the forces tending to close a parabolic valve are produced by fluid velocity creating variable low-pressure areas around the plug. A qualitative analysis of these forces is given in Fig. 14. This is a scale drawing of a percentage parabolic plug at rated lift. As the fluid leaves the restriction between the plug and the seat, it contracts to form a jet and produces a low-pressure area. This low-pressure area produces a force pulling the plug roughly at right angles to the plug contour point being considered. This force is shown by a dotted line at an angle from the centerline of the plug.

To form a picture of the net effect of this force, the vec-

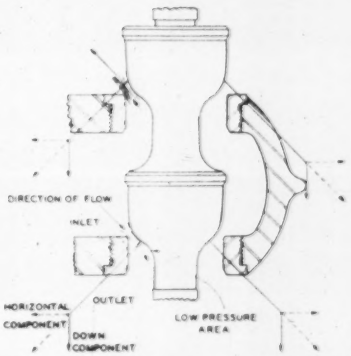


Fig. 14. Parabolic Plug Qualitative Force Analysis.

tor components have been resolved along the coordinate axes. These component forces exist around the entire circumference of the plug. Thus, for every horizontal force there is an equal horizontal force in the opposite direction. This cancellation of forces results in complete horizontal equilibrium. The net resultant is a force tending to close the valve and equals the summation of all downward vector components around the circumference. Notice how the fluid velocity produces forces on both the upper and lower plugs tending to close the valve ports.

Variations in the plug contours will modify the force-lift curve and the equilibrium position, but the general character and value of the forces are not materially altered.

V-port Plug Tests

The net stem force on a 4-in. single-seated percentage V-port plug for 100 psi. pressure drop is shown in Fig. 15. Sketch "A" identifies the valve construction with the flow entering under the seat tending to open the valve. The net change in force for the V-port plug is 260 lbs. compared with

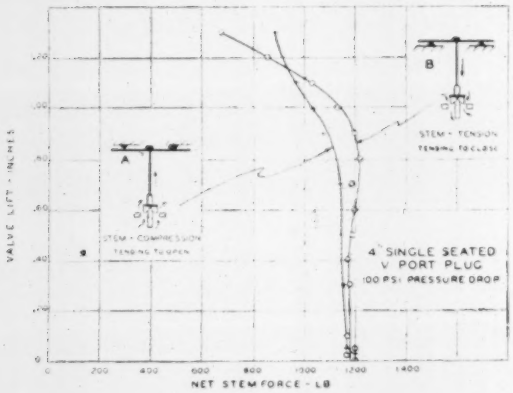


Fig. 15. Single-seated V-port—Lift vs. Force.

1010 lbs. for the parabolic plug. With the flow over the seat, Sketch "B," the net change, especially above 1-in. lift, is greater than when the flow was introduced under the seat.

To predict the behavior of a double-seated V-port valve, the graph shown in Fig. 16 was developed from the test data of Fig. 15. Up to 1-in. lift this force closely duplicates the measured force on a double-seated V-port valve. Above 1-in. lift the developed curve reverses from a force to close to a force to open. This force reversal did not occur on the double-seated test as shown in Fig. 17. The net stem force for the double-seated V-port is a relatively small percentage of the force existing in the parabolic plug.

Quick-opening Plug Tests

Fig. 18 gives the force curve for the single-seated quick-opening plug. For both flows over and under the seat, the stem force drops off at a fairly constant rate up to 1¼-in. lift. It should be borne in mind that this lift is much more than the theoretical required to expose full seat area. Considered in combination as a double-seated valve, there would be relatively little unbalanced force. The higher force tending to close would tend to cancel out the opening force caused by the differences in seat area for the closed condition. Note in the region of 0.1-in. lift that the two forces are not equal as they were in the case of the parabolic and V-port tests. The force tending to close increases rapidly above the theoretical and then drops off. In practice, this little hump is evidence of a definite tendency to suck the plug into the seat when the valve is operating at low lift.

Fig. 19 is the lift-force curve of a 4-in. double-seated quick-opening plug. At 6 percent lift, the net stem force curve reverses abruptly. This characteristic is similar to that observed in the two curves of the single-seated plug in Fig. 18. This substantiates the instability that is frequently observed when quick-opening plugs operate close to the seat. Fortunately, the magnitude of the force is small and gen-

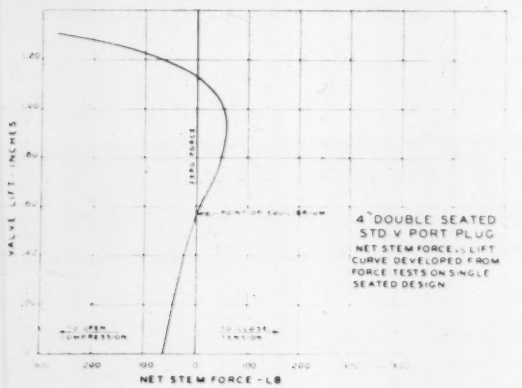


Fig. 16. Double-seated V-port—Lift vs. Net Force, from S.S. Data.

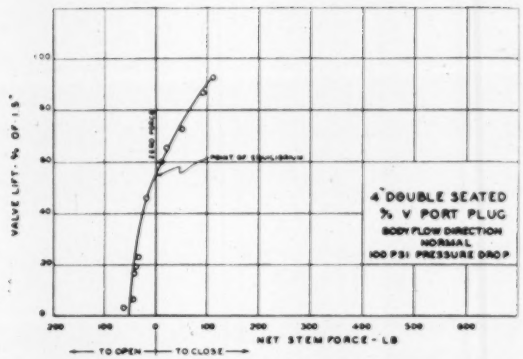


Fig. 17. Double-seated V-port—Lift vs. Force—Test Data.

erally not troublesome. The net change in stem force is only 65 lbs.

Special Overlapping Quick-opening Plug Tests

Fig. 20 is the lift-force graph for a special overlapping quick-opening plug. This plug was designed to study bad construction. The hump in the curve tending to close the valve mentioned in the discussion of the quick-opening

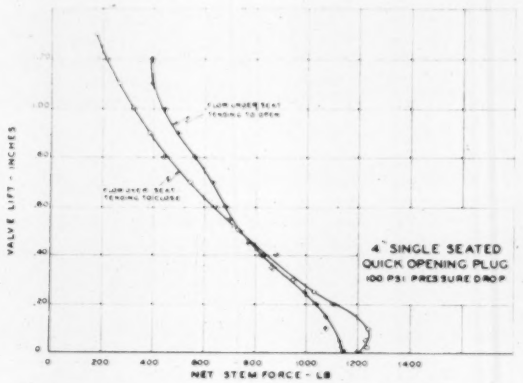


Fig. 18. Single-seated Quick-opening—Lift vs. Force.

plug is now very pronounced. Above 0.10 in., this force drops off very rapidly and above 0.3-in. lift the character of the force curves on the three quick-opening types is generally quite similar. In service, either as a double-seated valve, or as a single-seated valve with the flow over the seat, this valve would be extremely unstable. Both the magnitude of the force and the slope of the force curves contributes to this instability. This plug was not tested

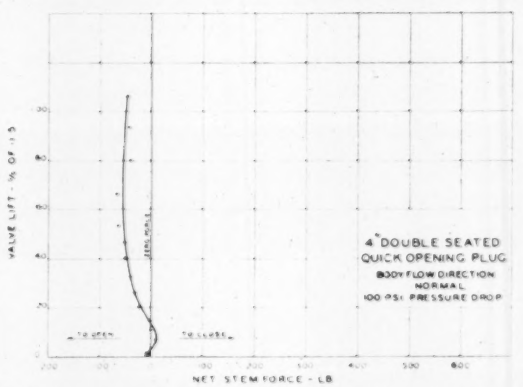


Fig. 19. Double-seated Quick-opening—Lift vs. Force—Test Data.

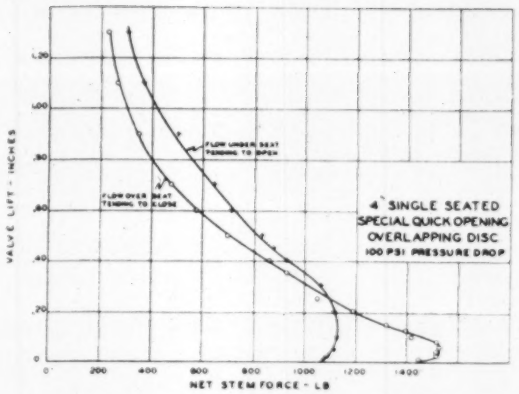

VALVE LIFT - INCHES
NET STEM FORCE - LB
FLOW UNDER SEAT TENDING TO OPEN
FLOW OVER SEAT TENDING TO CLOSE
4" SINGLE SEATED
SPECIAL QUICK OPENING
OVERLAPPING DISC
100 PSI PRESSURE DROP

Fig. 20. Single-seated Special Quick-opening—Lift vs. Force.

for stability because of the likelihood of severe damage to the test equipment.

Cup-shaped Plug Tests

The force test for a single-seated cup-shaped plug is shown on Fig. 21. This design has been used in turbine governor valves. The flow restriction is a sharp edge and there is no tendency to develop suction near the seat. The graph shows quite clearly that the force drops off rapidly with increased lift. The drop-off is almost identical to that of a single-seated quick-opening plug. Note that there is no tendency for a hump in the force curve with the flow over the seat as existed in the quick-opening plug design. This should give greater stability near the seat which may easily be a critical point in turbine governor valve design.

Spring-loaded Diaphragm-motor Valves

Single-seated:

The travel characteristics of spring-diaphragm motors are described in terms of air pressure range for rated stroke under no load conditions. The proposed ASA standard air range for spring diaphragm motors is 3 to 15 psi. When operating a single-seated control valve the air pressure vs. travel characteristics of the motor is altered by the plug force reactions. This alteration is a direct function of the net stem force and the effective area of the diaphragm.

In Fig. 22 this effect is shown for a typical system based on the force data obtained in these tests. For convenience the seat ring area is assumed to be 10 sq. in., and the diaphragm-motor effective area 100 sq. in. A plot of the diaphragm-motor characteristic is shown as a straight line from 3 to 15 psi. for 100 percent lift.

Flow over the Seat Tending to Close:

In Sketch "A" with the flow over the seat, the force reaction on the valve plug acts to compress the diaphragm-

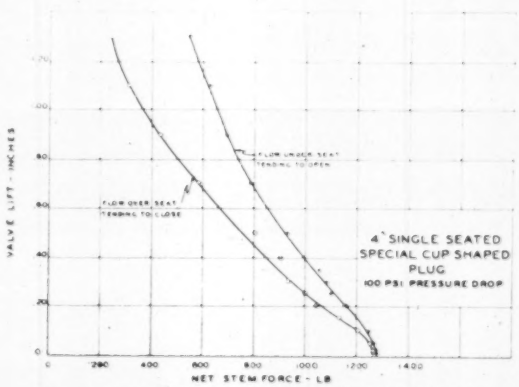

VALVE LIFT - INCHES
NET STEM FORCE - LB
FLOW UNDER SEAT TENDING TO OPEN
FLOW OVER SEAT TENDING TO CLOSE
4" SINGLE SEATED
SPECIAL CUP SHAPED
PLUG
100 PSI PRESSURE DROP

Fig. 21. Single-seated Special Cup-shaped—Lift vs. Force.

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Well Type Manometer
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Well Type Manometer
(Front-of-Board Mounting)

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One piece sockets—to fit all stem lengths

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—70 to 150°F. 0 to 500°F.	—10 to 110°C.	—70 to 56°C.
0 to 200°F. 150 to 750°F.	0 to 150°C.	
0 to 300°F. *200 to 1000°F.	0 to 300°C.	
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*Not recommended for continuous operation above 800°F.

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motor spring lowering the diaphragm air pressure for any given plug position. With a differential pressure of 90 psi. and the plug just off the seat, the net stem force tending to close the valve and compressing the spring is 900 lbs. This is equivalent to 9 psi. on the diaphragm and the valve starts to open at 15 minus 9, or 6 psi. From test data of known forces occurring at various lifts, the complete curve can now be developed.

Note that the actual spring range of the motor is now minus 1.5 psi. to 6 psi. for a spread of only 7.5 psi. against 12 psi. for no-load. The 4.5-psi. loss is due to the change in force on the plug as it moves through the stroke. Actually, this theoretical curve can never be realized in practice, since the valve will not open beyond 55 percent lift. At this position the spring force is 825 lbs. opposed by the plug stem tension of 825 lbs. and the force system is in equilibrium.

The point to be emphasized is the fact that with the flow over the seat (tending to close) it is axiomatic that the air pressure range is reduced. This reduction in actual air pressure range with the flow over the seat is the dangerous one. In many actual cases this reduction, if severe, can actually cause a reversal, which will give the equivalent

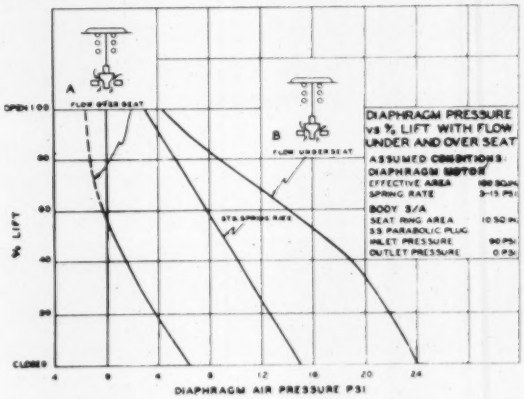

Fig. 22. Spring Diaphragm Motor—Pressure vs. Lift.

of snap action to the valve plug. If the rate of force change on the plug as it moves through the stroke is greater than the spring coefficient, this instability is bound to occur. The 4-in. single-seated parabolic plug showed a maximum rate of change of force of 1100 lbs. per in. at 100 psi. pressure drop. The spring rate for a 1¼-in. stroke, 100 sq. in. motor, 3-15 psi., is only 1000 lbs./in., whereas for stability it should materially exceed 1100 lbs./in. Naturally, certain plug types are more favorable in this regard than others, but too little quantitative data are available for any general rule.

Another effect more difficult to measure and analyze, but very real, is the dynamic force induced by the accumulative or "lock-up action" of such valve installations. As the plug approaches the seat, the net stem force increases, tending to pull the plug into the seat to further increase the stem force. On many installations this action may be coupled with an almost instantaneous transfer of line loss and body loss to the plug and seat ring, and the result is a water hammer effect of tremendous force. When the plug hits the seat, pressure surges in the line will release the force almost instantaneously and the cycle will repeat, causing a violent chatter.

Flow Under the Seat Tending to Open:

With the flow under the seat in Sketch "B," the stem force is in the same direction as the spring force raising the required diaphragm air pressure for any plug position. The resultant curve runs from 24 psi. in the closed position to about 4.5 psi. in the open position. This gives an actual air pressure range of 19.5 psi. compared with 12 psi. for the no-load condition. The equivalent air pressure due to force change in this case is 7.5 psi. This is true

whether the plug is right side up, as has been shown in these sketches, or reversed in position.

With the flow under the seat, the change in force on the valve plug through the stroke acts to increase the air pressure range. This gives the system an inherent stability. Any motion of the valve plug produces a force change which tends to oppose further motion. This is the "self-regulating" tendency found in many control processes.

As a practical example, the 4-in. single-seated parabolic plug in the test was run with the flow under the seat through full stroke using a 100 sq. in. diaphragm motor with the actuating air pressure to the top of the diaphragm pushing the plug shut. The water supply pressure was maintained at 160 psi. with zero psi. downstream. The motor was a springless type with no loading pressure to the underside of the diaphragm. Under these operating conditions, the off-balance force on the plug when operating near the seat was approximately 1800 lbs. or 18 psi. on the diaphragm. This is a very substantial load, yet the valve could be operated erratically and rapidly through full stroke without the slightest tendency to instability. This same plug with the flow in the opposite direction at only 100 psi. drop slammed violently enough to endanger the whole piping system.

Double-seated Valves:

Both the analysis based on single-seated valve tests and the actual results on the double-seated valves show conclusively that substantial vertical forces are developed only with the parabolic solid turned type of plug. These forces can be substantial and severely limit the application of this plug shape in the larger sized diaphragm-motor valves operating under high pressure drops. The quick-opening disk and various skirted plug designs give very little net vertical force. The skirted type plug does develop a rotational force which fortunately can be greatly reduced by proper design.

Springless Diaphragm-motor Valves

Single-seated:

Fig. 23 shows the air pressure vs. stroke characteristic of the 4-in. single-seated parabolic plug operated by a conventional springless motor. In the springless motor the variable spring loading is replaced by a constant air loading; in this case arbitrarily set at 5 psi. Under no-load conditions the actuating air pressure vs. stroke would be a constant line at 5 psi. on the assumption that there is no weight of parts or change in effective area.

Flow Over the Seat Tending to Close:

In Sketch "A" with the flow over the seat tending to close, the actuating pressure is brought in to the under diaphragm to push the plug open. Both the 5-psi. loading pressure and the off-balance on the plug equivalent to 9 psi. oppose the actuating pressure and the initial is 14 psi. The resultant diaphragm pressure test curve developed from the force data varies from 14 psi. at zero lift to 9 psi. at rated lift.

One important limitation of the pneumatically-loaded system with this body flow path is its inherent instability. This tendency towards instability due to the "lock-up action" is very pronounced. The pressure build-up and consequent plug motion are so rapid that no compensating action by the motor positioning mechanism is possible. It is significant that the four single-seated plug types vibrated severely when tested in this manner. The motor used on these tests was a 100 sq. in. unit equipped with a positioner with and without a relay. In this respect the springless motor is probably less satisfactory than the spring loaded type.

Flow Under the Seat Tending to Open:

With the flow as shown in Sketch "B" the actuating pressure is introduced on top of the diaphragm to push the valve closed against flow. The effect of the force acting on the plug, therefore, is to increase the required actuating pressure so that the initial again becomes 14 psi. (5 psi. plus 9 psi. for the 900-lb. force). The shape of the char-

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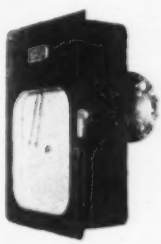

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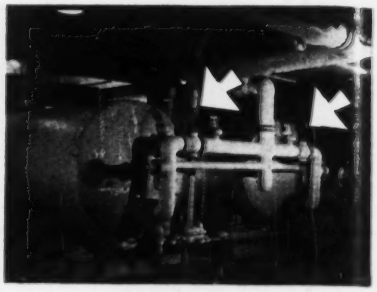

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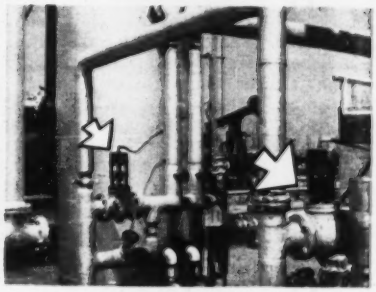

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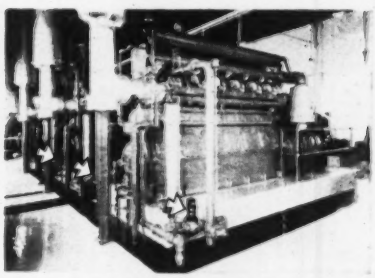

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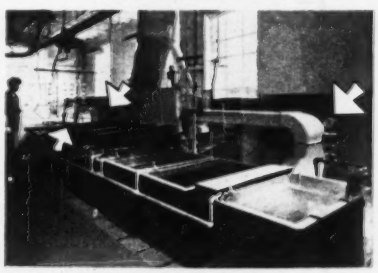

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acteristic curve is determined by the force curve on the plug itself. The resultant diaphragm pressure curve varies from 14 psi. at zero lift to 6.5 psi. at rated lift.

Although this change in pressure is greater than with the flow over the seat, the valve is inherently stable, possessing self-regulation as discussed under spring diaphragm motors.

By using various combinations of loading pressures and direction of actuating, these characteristic curves can be shifted or reversed in shape but not altered in character. As a typical example under Sketch "A," the actuating air pressure could have been brought in on top of the diaphragm to force the valve in the closing direction. The 900-lb. force on the plug when operating near the seat now acts in the same direction as the actuating pressure and the loading pressure of 5 psi. would have to be increased by 18 psi. to 23 psi. in order to produce the 14 psi. initial pressure. The actuating pressure would tend to increase as the plug force dropped off rather than decrease. The net change would be the same.

In actual practice, under such operating conditions the loading pressure would be set at some lesser value to bring the actuating pressure into a good operating range. By thus shifting the direction of application of the actuating

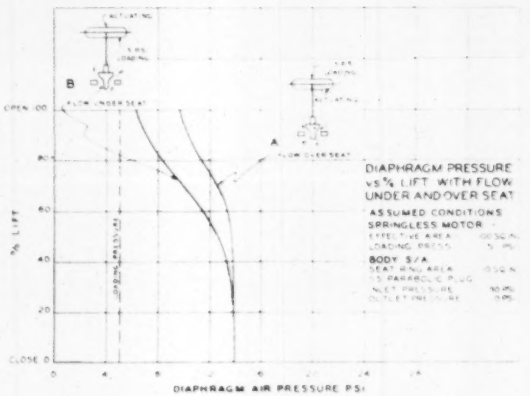

Fig. 23. Springless Diaphragm Motor—Pressure vs. Lift.

pressure and the magnitude of the loading pressure (or both) the springless motor can be made to exert a much larger useful thrust than the spring type motor of equivalent effective area.

To simplify the problem of selection of the correct loading pressure and direction of actuation, springless motors are sometimes equipped with a reversing relay which automatically applies a variable loading pressure to the opposite side of the diaphragm in inverse proportion to the actuating pressure. The actuating and loading pressures are equal at one adjustable point only, usually at the mid-range. The off-balance force on the plug is then counterbalanced by both the loading and the actuating pressures in equal proportions. The relay also tends to increase the rate of response of the motor, but it does not increase the potential power of the motor or its stability.

Unfortunately, it is not always possible to choose the direction of flow through the body independently. In angle valve design for high pressure drop service, the flow is brought in over the seat. By reversing the flow, a substantial part of the erosive resistance and free flow character of the valve is lost. With the flow in over the seat with spring or springless motors, the application of the valve is severely limited by this tendency to instability.

Double-seated Valves:

Since the double-seated valves do not require large operating forces there is less reason to consider the use of springless motors. Generally speaking, almost any industrial application can be handled by a valve operated by the simpler spring motor.

Continued on page 1288

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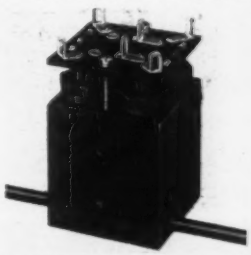

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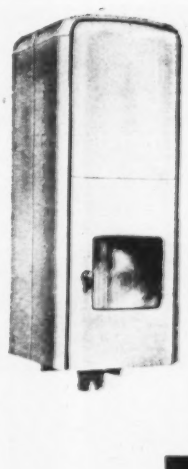

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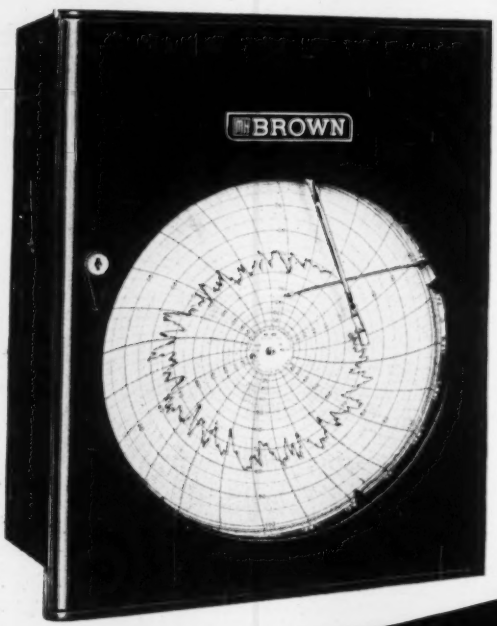

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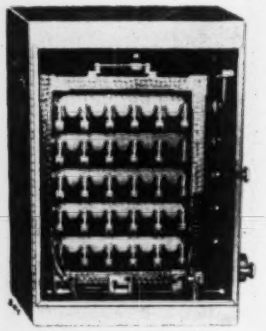

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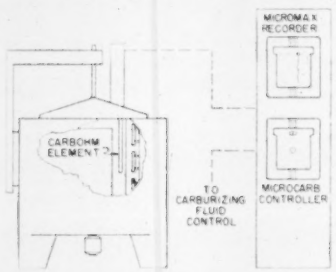

detecting element, which projects into furnace work chamber, and electrically "senses" carburizing potential of furnace atmosphere. Element is connected to "Microcarb" controller, which adjusts flow of carburizing fluid to hold carbon potential of furnace gas at any selected value between 0.15 and 1.15 percent carbon. A "Micromax" recorder draws a continuous record of percent carbon as detected by "Carbohm" element.—*Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa.*

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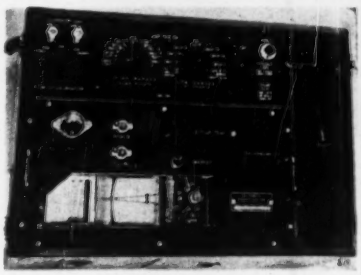

has 22 ranges from 0.25 micro-micro-amp. to 10 amp. Other recorders cover from 1 mv. to 1000 v., and 10 microvolts to 1 v. Frequency response is within 3 db at 20 cps. Chart is 5 cm wide; standard paper speeds are 10 or 25 mm. per sec.—*Millivac Instrument Corp., P. O. Box 3027, New Haven, Conn.*

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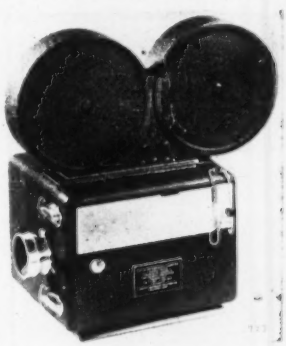

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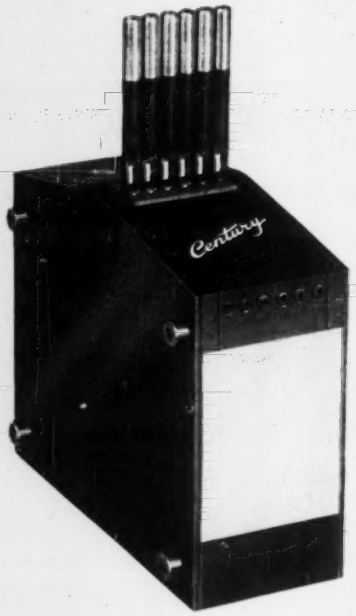

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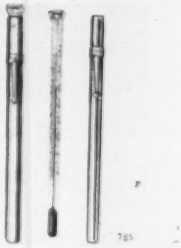

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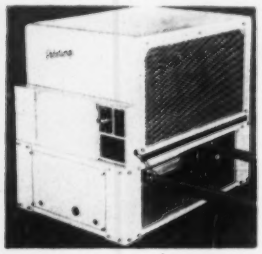
Fluid Temperature Control Unit

New "Pakotemp" device controls fluid temperature within 0.5 deg. F., by forced circulation of a tempering liquid



through jacket of vessel containing fluid. Unit can heat or cool tempering liquid; requires one electrical connection and two pipe connections to vessel. —*Pako Corp., 1010 Lyndale Ave. N., Minneapolis, Minn.*

Mention No. 1410 when filling out card.

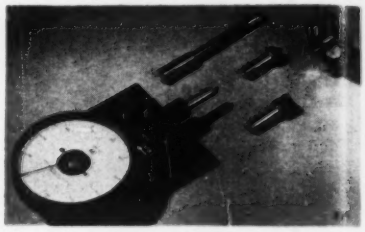
High-speed Decimal Counting Units

New "Models 706 and 707" decimal counting units have maximum rates of 200,000 and 1,000,000 pulses per sec., respectively. Model 706 has a 2.5 microsec. resolution of pulse pairs; model 707 has 0.8 microsec. resolution. Both units are designed for scale-of-10 operation.—*Berkeley Scientific Co., 23rd and Wright Sts., Richmond, Calif.*

Mention No. 1411 when filling out card.

Dual-range Tachometer

New "Model A.T.H. 10" hand tachometer has ranges to 1000 and 5000 rpm., selected by switch. Alnico magnet

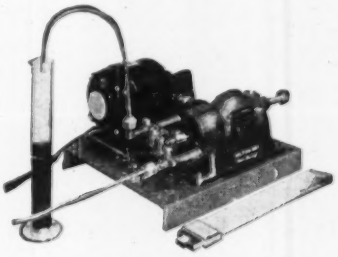


revolving inside drag cup gives speed indication. Accuracy is 0.5 of 1 percent over entire range. Pushbutton holds pointer at speed indication.—*Equipoise Controls, Inc., 100 Stevens Ave., Mount Vernon, N. Y.*

Mention No. 1412 when filling out card.

Miniature Controlled-volume Pump

New "miniPump" capacity can be varied from 3 to 800 cc. per hr., at pressures up to 1000 psi. Liquid end



and plunger are Carpenter 20 stainless steel; ball checks may be glass, type 440 stainless steel, or synthetic sapphire. Pump may be driven by electric motor or air cylinder.—*Milton Roy Co., Philadelphia 18, Penna.*

Mention No. 1413 when filling out card.

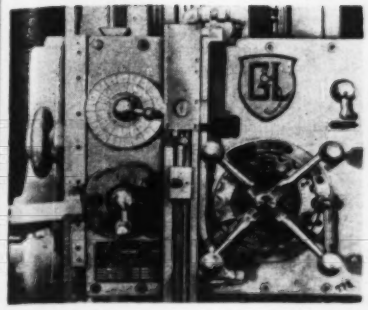
Controlled Temperature Unit

New packaged variable temperature unit is designed for use with material testing machines; is accurate to 1 deg. F. New unit is part of maker's line for producing temperature-controlled air from –90 to 350 F.—*Tenney Engineering, Inc., 26 Ave. B, Newark, N. J.*

Mention No. 1414 when filling out card.

Electrically-operated Positioning Device

New electrically-operated positioning device makes precision settings of table and headstock of maker's horizontal boring machine, using separate control unit for each. In operation, end-measuring rods are mounted on machine to indicate desired work and tool positions. Machine directional controls are manually engaged, and table and headstock

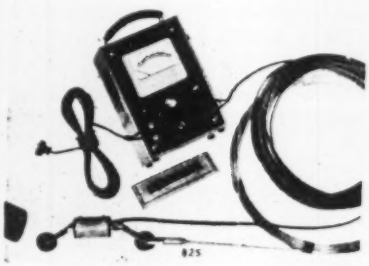


move in rapid traverse until directional clutches are disengaged by selector switches, with 0.005 to 0.010 in. overtravel. Through a magnetic clutch, fine feed returns table to within 0.0002 to 0.0005 in. of desired setting.—*Gidding & Lewis Machine Tool Co., Fond du Lac, Wis.*

Mention No. 1415 when filling out card.

Boiler Scale Thickness Indicator

New instrument measures scale thickness in boiler tubes; electromagnetic probe head is passed through tubes



with a graduated steel tape. Distance between side of probe head and tube wall is indicated in thousandths of an inch. Unit will also indicate pitting and corrosion.—*Haskins Turner Co., 1617 Third St., Jackson, Mich.*

Mention No. 1416 when filling out card.

Electric Interval Timer

New electric interval timer for darkroom processing resets by turning a knob on front of case; pointer moves back to pre-set starting place and starts timing. Red glow lamp indicates when timer is operating; at end of interval an electric buzzer sounds until shut off. —*General Electric X-Ray Corp., 4855 Electric Ave., Milwaukee 14, Wis.*

Mention No. 1417 when filling out card.

Manual Preset Time Switch

New "Type J3" timer automatically switches an electrical circuit either "on" or "off" after a time interval set on a calibrated dial. Releasing knob starts timer, and pointer is driven back towards zero by a synchronous motor.

PLUS VALUES IN

Helicoid Gages

This Vacuum Gage is an example of the extra value at no extra cost in all Helicoid Gages.

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2. Subdivisions in graduated steps of 0.2 inches for ease in reading scale.
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4. Guaranteed accuracy to within 0.15".
5. The new square flush case.

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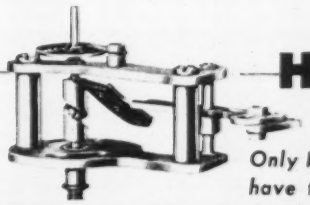

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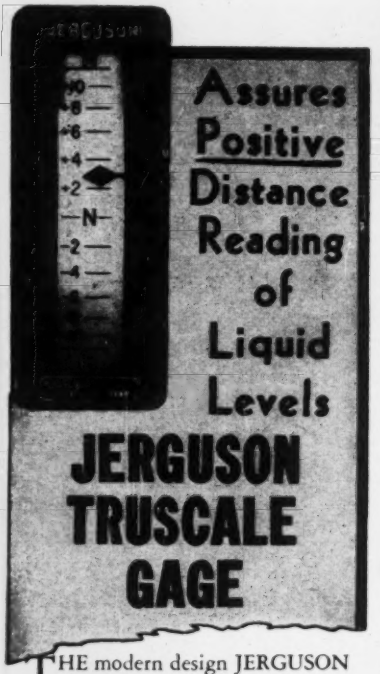

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Hydrostatic type distance reading gage with inverted U-tube manometer. Water level always visible with space above showing brilliant red. Built-in feature makes possible checking of gage accuracy in few seconds.

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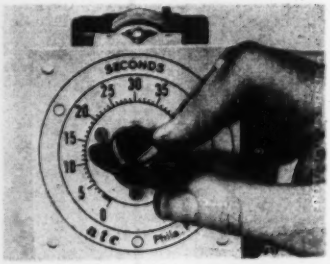
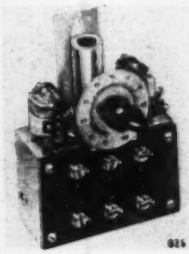


At zero position, a snap-acting switch is tripped and timer is shut off. Standard dial ranges available are 0 to 15 sec. to 0 to 24 hr.—*Automatic Temperature Control Co., Inc.*, 5212 *Pulaski Ave., Philadelphia* 44, *Pa.*

Mention No. 1418 when filling out card.

Electronic Timer

New "Model CK" electronic timer uses type 5823 cold-cathode tube. Time ranges of 1.5, 3, 6, or 12 sec. are available; dial is set for desired percent of



total range. Timer operates from 105-125 v., 60 cps., line; s-p.d-t. switch is rated 8 amp., 125 v., non-inductive load.—*Farmer Electric Co.*, 21 *Mossfield Road, Waban* 68, *Mass.*

Mention No. 1419 when filling out card.

Variable Discharge Metering Pump

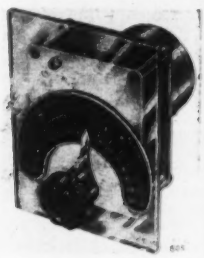
New metering pump is a variable discharge spur gear type equipped with a single revolution clutch. When clutch lever is depressed, gears are driven by motor through pawl and ratchet mechanism. Amount discharged per stroke is changed by setting a cam which is locked in position by a spring-loaded pin, mounted on a graduated index sector. Thermostatically con-

trolled strip and cartridge heaters are provided around tank, in gear housing, and at nozzle to produce temperatures up to 450 F. Metering range available is from 0.0154 to 12.50 fluid oz. per stroke; accuracy is 3 percent.—*Edward E. Robinson, Inc.*, 95 *Park Ave., Nutley* 10, *N. J.*

Mention No. 1420 when filling out card.

Automatic Interval Timer

New "Type IG" interval timer stops manually-started electrical equipment after a pre-set time. Timer operates one or two s-p. d-t. switches and re-



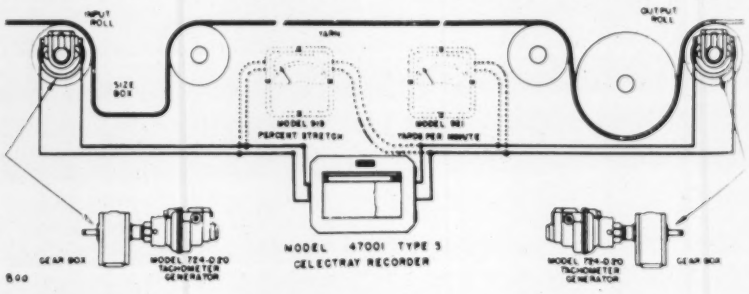
turns to original position at end of time interval. Timer is available with eleven time ranges, from 15 sec. to 24 hr.—*R. W. Cramer Co., Inc., Centerbrook, Conn.*

Mention No. 1421 when filling out card.

"Stretchmeter" for Materials in Process

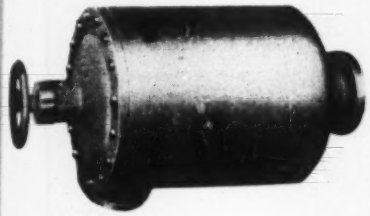
New recording speed-ratio tachometer gives percentage stretch or shrink of materials processed between pairs of rolls turning at different speeds. Tachometer generators driven by each roll transmit to a "Celectray" ratio recorder, calibrated in desired units.—*Dep't* 414, *Tagliabue Instrument Div., Weston Electrical Instrument Corp.*, 614 *Frelinghuysen Ave., Newark* 5, *N. J.*

Mention No. 1422 when filling out card.



Fluid-flow Regulator

New flow regulator is direct acting and requires no air or electric circiuts; power for control action is supplied by

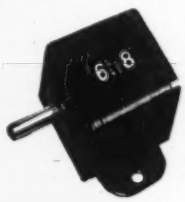


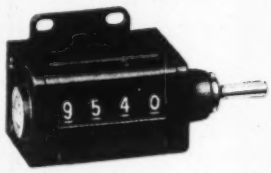
fluid passing through the regulator. Instrument shown handles 300 gpm.; smallest regulator controls flow down to 0.1 gpm.—*W. A. Kates Co., 430 Waukegan Road, Deerfield, Ill.*

Mention No. 1423 when filling out card.

Instrument-application Counters

New "Model Y" counters are designed for use in radar and navigation instru-





ments. Four dial unit illustrated has figures offset from vertical to provide better reading angle.—*Durant Mfg. Co., 1929 N. Buffum St., Milwaukee 1, Wis.*

Mention No. 1424 when filling out card.

Time Switch

New time switch combines electric and spring drives; if electricity fails, spring driven unit goes into action. Instrument turns electrical equipment on and off at any pre-set time, once in

Here may be the answer to your RECORDING problem

Sanborn Amplifier Recorders are being found outstandingly useful in a wide variety of industrial recording applications. Records are produced *directly*, and continuously, by *heated stylus* on plastic coated record paper (Permapaper), are in *true rectangular* coordinates, and are sharp, clear, and *permanent*. Elimination of the *ink flow* type of recording permits the use of these recorders in any position and at any angle. The writing arm (or arms) is driven by a D'Arsonval moving coil galvanometer with an extremely high torque movement (200,000 dyne cms per cm deflection).

The single channel Model 128 is a vacuum tube recording voltmeter capable of reproducing electrical phenomena from the order of a few millivolts to more than 200 volts. Standard paper speed is 25 mm/sec. Slower speeds of 10, 5, and 2.5 mm/sec. are available. A variety of interchangeable amplifiers is available.

The multi-channel Model 67 provides for the simultaneous registration of *up to four* input phenomena on one record using, in a multiple system, the same principles and methods as the single channel Model 128.

In addition, this vertically mounted, metal cased amplifier-recorder provides a choice of eight paper speeds: 50, 25, 10, 5, 2.5, 1.0, 0.5 and 0.25 mm/sec., and further provides for the use of 4-, 2-, or 1-channel recording paper. Complete versatility of recording is offered in this unit by means of interchangeable amplifiers which permit the registration of stresses, strains, velocities, etc., along with the usual D.C. or A.C. phenomena.

The recorder and amplifier units of which the above models are comprised are also available separately.

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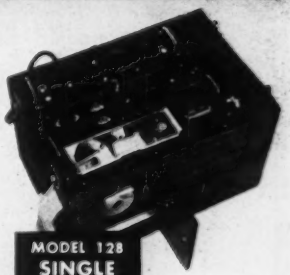

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ANSWERING THOUSANDS OF VITAL QUESTIONS CONCERNING OSCILLOSCOPES

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An outstanding feature of this book is a most useful and comprehensive compilation of 1600 complex waveform patterns listing the harmonics and the exact phase and amplitude of each. This information has **NEVER BEFORE BEEN PUBLISHED!** All 'scopes produced during the past 10 years, a total of more than 70 different models, are clearly described—with specifications and schematic wiring diagrams.

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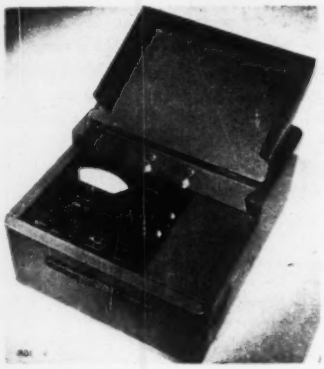
every 24 hrs; dial is calibrated in 15 min. intervals. S-p. switch is rated 20 amp. Over-all dimensions 5 x 9 x 4 in. Steel case is dust and drip-proof.—*Dep't 7, Hagen Mfg. Co., Baraboo, Wis.*

Mention No. 1425 when filling out card.

Multi-range Fluorimeter

New photoelectric fluorimeter has linear sensitivity over a wide range; indicating instrument readings can be expanded up to 100 times by a dial switch. Microquantities can be analyzed

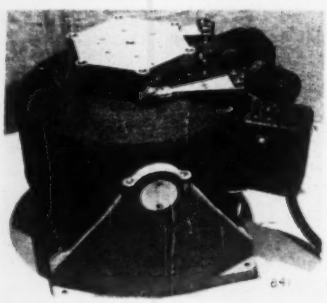


even though selective optical filters are used. Cuvette carrier holds a 15 mm. Pyrex test tube, and 2 x 2 in. optical filters. Instrument operates from a-c. line, with internal voltage regulation. Over-all dimensions 20 x 23 x 12 in.—*Central Scientific Co., 1700 Irving Park Blvd., Chicago 13, Ill.*

Mention No. 1426 when filling out card.

Shaker and Power Supply

New "Models 44 and 45" shaker and power supply are designed for vibration testing from 2 to 500 cps. with acceleration to 50 g. Shaker develops 20 g with 14 lb. load; it has 450 lb.

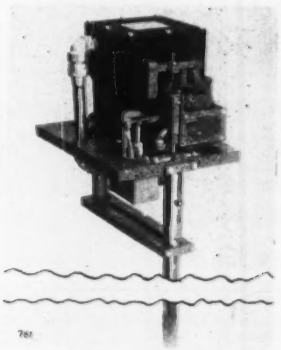


vector force output with 40 C. armature temperature rise. Variable-speed d-c. motor drive alternators for shaker power supply. Control console for rotary equipment houses field control, current meter, and shaker phasing switch. Unit operates on 220 or 440 v. 3 phase.—*The Calidyne Co., 751 Main St., Winchester, Mass.*

Mention No. 1427 when filling out card.

Viscometer for Explosion-proof Applications

New measuring element for major's viscometer meets Class I, Group D explosion-proof requirements. Element

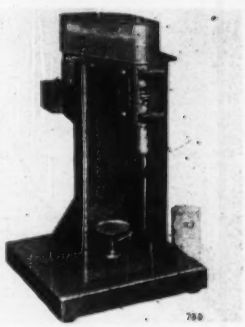


can be furnished with recorder or automatic controller.—*Norcross Corp., 247 Newtonville Ave., Newton 58, Mass.*

Mention No. 1428 when filling out card.

Latex Stability Test Apparatus

New latex test apparatus determines mechanical stability of concentrated natural latices. Unit consists of vertical shaft stirrer operating at 14,000 rpm.



Agitator is highly polished stainless steel disk threaded to spindle shaft; spindle is driven by 0.5-hp. induction motor. Pyrex test jar has side hole for sampling.—*Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.*

Mention No. 1429 when filling out card.

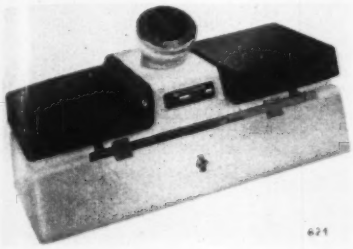
Sub-zero Chilling Unit

New "Model R-120" chilling unit can be adjusted to temperatures from 0 to minus 120 F. Chilling chamber is 18 x 30 x 33 in.; is insulated with Santocel; has a capacity of 2000 B.t.u. per hr. Unit operates on 220 v., three phase, a.c.—*Sub-Zero Products Div., Deepfreeze Distributing Corp., 3928 Reading Road, Cincinnati 29, Ohio.*

Mention No. 1430 when filling out card.

Balance

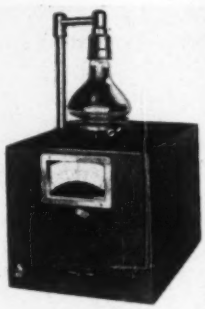
New "Metrogram" weighing instruments are available in four models for loads from 5 to 25 lbs., with sensitivities of 50-200 mg. Features include optically flat carboloy bearing surfaces, and carboloy knife edges; air damping is used in all models.—*H. A. Hadley Associates, Inc., 25 Pearl St., Burlington, Vt.*



Mention No. 1431 when filling out card.

Moisture Tester

New moisture tester is single pan balance; sample is dried by radiant heat while on pan. Balancing dial is direct reading in percent moisture.—*Claud S. Gordon Co., 3000 S. Wallace St., Chicago 16, Ill.*



Mention No. 1432 when filling out card.

Helium Cryostat

New Collins helium cryostat uses helium at 225 psi. maximum pressure as refrigerant. Experimental chamber temperature can be varied between 2 and 300 deg. K; helium and other gases can be liquified at rates up to 4 liters per hr. Components include liquid nitrogen charcoal trap, low pressure gasometer, 15-hp. 4-stage compressor, and liquifier.—*Arthur D. Little, Inc., 30 Memorial Drive, Cambridge 42, Mass.*

Mention No. 1433 when filling out card.

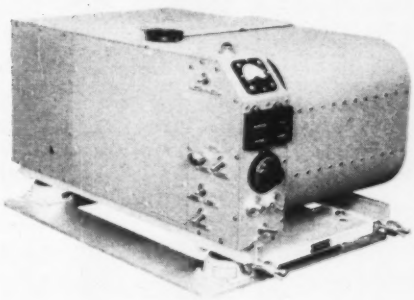
Combustible-gas Indicator

New "Vapotester Model M-1, Type 1" combustible-gas indicator operates on Wheatstone bridge circuit, with reference filament sealed in air. Analyzing filament is not poisoned by tetraethyl

Century INDUSTRIAL

RECORDING OSCILLOGRAPH

FOR VIBRATION, TEMPERATURE, STRESS, STRAIN ANALYSIS



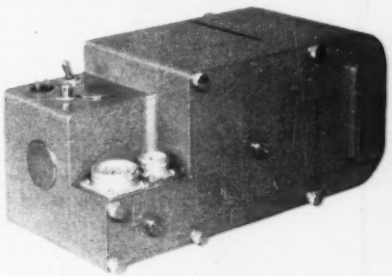
MODEL 408 OSCILLOGRAPH

The Century Model 408 recording oscillograph was designed expressly for airborne and mobile operation. As with all Century products, this oscillograph incorporates the utmost in design and workmanship, along with improved features, yet it remains simple in its operation and maintenance.

FEATURES:

- Size: 20" long, 12½" wide, 8⅞" high.
- Weight: 60 pounds.
- Number of Recording Channels: 6 to 50.
- Detachable daylight loading magazine accommodating a roll of paper or film 8" x 200'.
- Friction roller type paper drive by governor controlled electric motor with separate motor for takeup drive.
- Paper speeds continuously and instantly variable without changing gears or sprockets.
- Separate optical system for viewing before or during recording.
- Glow tube timing system photographing .01 second and .1 second lines. .01 second lines instantly removable by toggle switch for slower speeds.
- Data numbering at beginning of record.
- Footage indicator showing amount of paper remaining in magazine.
- Automatic record length control.
- Trace identification.
- Remote control unit.

MODEL 409 OSCILLOGRAPH



The Century Model 409 oscillograph has been designed for recording data where space and weight requirements are limited. This oscillograph has been tested to record faithfully while subjected to accelerations up to 20 G's.

FEATURES:

- Size: 5" x 5" x 11".
- Weight: 11 pounds.
- Cast Aluminum case.
- Paper speeds variable ½" to 12" per second.
- Detachable daylight loading magazine with a capacity of 3⅝" x 50' paper or film.
- 2 to 12 individual channels.
- Trace identification.
- Trace viewing.

For Complete Information Write 1340 North Utica

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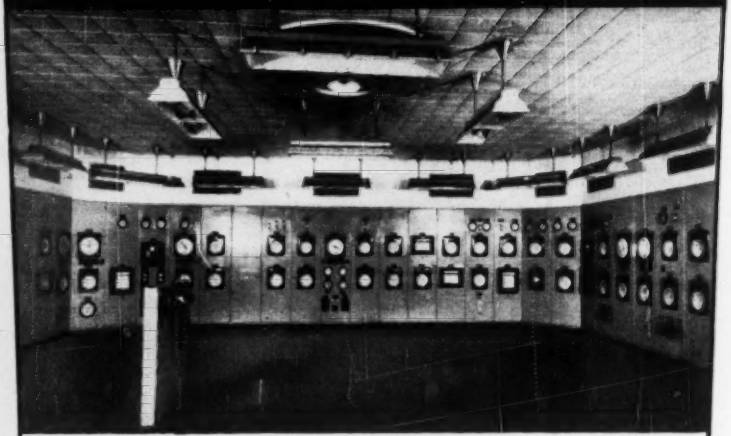

If you need an enclosure for one, two or three instruments . . . or hundreds of instruments, call on KIRK & BLUM for fast, accurate fabrication. The photo above shows a typical large installation. Almost 100 instruments and controls are visible in this installation in a major refinery.

KIRK & BLUM is equipped and experienced to fabricate one unit or hundreds, specializing in custom-built parts and assemblies of sheet steel, light plate, stainless, aluminum, monel and other alloys in gauges 3/8" and lighter.

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lead; instrument is UL approved for use on leaded gasolines.—*Davis Instrument Div., Davis Emergency Equipment Co., Inc., 45 Halleck St., Newark, N. J.*

Mention No. 1434 when filling out card.

Hops Moisture Tester

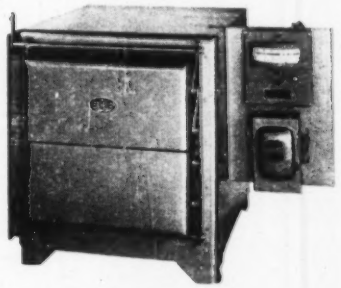
New "TAG-Heppenstall" moisture tester for hops operates on an electronic circuit. Instrument is designed for use in breweries; samples of hops are ne

weighed before testing.—*Dep't 67, Tagliabue Instrument Div., Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.*

Mention No. 1435 when filling out card.

Electric Furnace

New line of electric furnaces is equipped with wired control panel attached to furnace. Panel carries temperature controller, load relay, thermo-

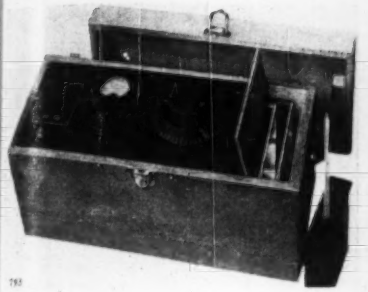


couple lead and fused disconnect switch. Either an automatic electronic pyrometer-controller, or a manually operated controller-indicator can be furnished. Furnaces operate to 1900 F.; feature more efficient insulation and improved design of heating elements.—*Thermo Electric Mfg. Co., 496 W. Locust St., Dubuque, Iowa.*

Mention No. 1436 when filling out card.

Cottonseed Moisture Tester

New "Model 8007" moisture tester is based on maker's dielectric moisture indicator. Instrument has one adjustment dial, and accuracy is not affected by fluctuating voltage. Available calibrations cover cottonseed in various



process stages. Instrument can be used for other materials.—*Dep't 67, Tagliabue Instrument Div., Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.*

Mention No. 1437 when filling out card.

Tumbler-mixer

New tumbler-mixer can be tilted to 90 deg. from vertical; adjustable clamps on turntable hold containers up

to 5 gal. can. Motor is 0.17 hp. 110 v. 60 cps.; shafts are mounted in anti-friction bearings.—*Arthur S. LaPine & Co., 121 W. Hubbard St., Chicago 10, Ill.*

Mention No. 1438 when filling out card.

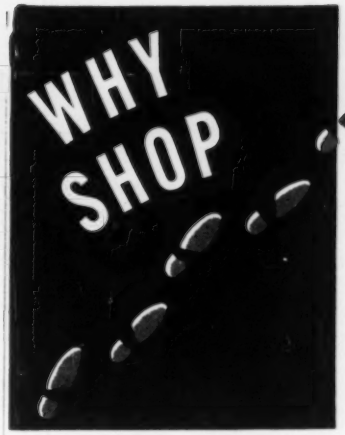
Seven-inch Monitor Kinescope

New "7QP4" 7-in. c-r. tube has magnetic focus and deflection. Tube features large screen area in relation to diameter, and an ion-trap gun requiring a single-field external magnet.—*Tube Dep't., Radio Corp. of America, Harrison, N. J.*

Mention No. 1439 when filling out card.

Miniature Electrical Indicating Instruments

New 1.5 in. VU and db indicating instruments are available in three styles; square waterproof case (illustrated), round waterproof case with



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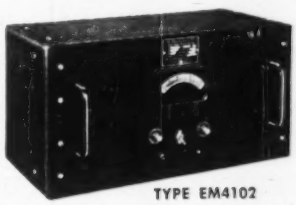
If you're looking for dependable automatic voltage regulation, investigate STABILINE first. You'll save time and money — you'll get longer service through better design and construction — you'll get performance and operating characteristics as advertised.

AVAILABLE IN 2 TYPES

STABILINE Type IE is instantaneous and completely electronic in action. Keeps output voltage to within ±0.1% of preset value regardless of wide line variations; to within ±0.15% regardless of load current or power factor changes. Waveform distortion *never* exceeds 3%. STABILINE Type IE is available in cabinet or rack mounting models — in numerous ratings.

TYPE IE PORTABLE



TYPE EM4102

STABILINE Type EM (Electromechanical) features zero waveform distortion, insensitivity to magnitude and power factor of load, no effect on system power factor; no critical adjustments. It is available in output ratings up to 100 KVA — for single and for 3 phase operation.

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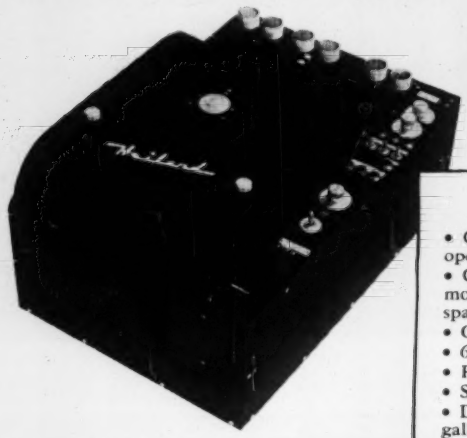

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FEATURES

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- Can be panel mounted
- 6 to 24 channels
- Paper widths 5", 8", 12", 18"
- Simplicity of loading
- Direct monitoring of galvonometer light spots
- Flexibility of operation
- Simultaneous viewing, recording and scanning
- Trace identification...zero mirror...synchronizing reference trace
- Adjustable automatic record length

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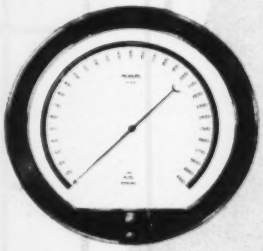

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Heise pressure gauges employ an infinite number of Bourdon tube designs to reduce fibre stress to a point where the gauge can be used continuously at maximum calibration. There is no standard design. Every Heise Bourdon tube is designed for maximum stability and accuracy in a selected range and pressure medium.

Three sizes: 8½ in., 12 in., and 16 in., in ranges from 0-15 to 0-10,000 psi. Prices from $151.60 to $211.20. Write for catalog.

Heise Bourdon Tube Company, Inc.
Newtown, Connecticut

"O" ring seal, and round flange-mounting case with commercial type of seal. D'Arsonval-type movement is insulated for 1500 v. Scales have arc length of 1.3 in.; are available black on white, or reverse.—*International Instruments, Inc., 331 East St., New Haven 11, Conn.*

Mention No. 1440 when filling out card.

Electrical Indicating Instruments

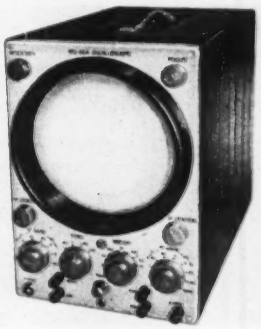
New "Types AB-16 (a.c.) and DB-16 (d.c.)" instruments are 8.75 in. models, with 250 deg. scales, 14.2 in. long. Scale is mounted flush with front of case;

a protruding convex glass cover provides clearance for scale and pointer. Cases are dustproof and moisture-resistant; movements are magnetically damped, with shock-resistant bearings. —*Meter and Instrument Div., General Electric Co., Schenectady 5, N. Y.*

Mention No. 1441 when filling out card.

Seven-inch Oscilloscope

New "Model WO-56A" CRO features three push-pull stages of direct-coupled amplification. Coarse and fine controls are on concentric shafts. High fre-



quency response up to 100 kc. is obtained without peaking coils; low frequency response is flat down to d.c. Vertical amplifier can be calibrated for 1 in. deflection for 10.6 rms mv. Sweep trace may be expanded three times screen diameter.—*Tube Dep't., Radio Corp. of America, Harrison, N. J.*

Mention No. 1442 when filling out card.

Seven-inch Oscillograph Tube

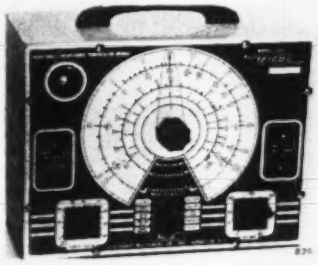
New "7JP1" 7-in. c-r. tube has electrostatic focus and deflection electrodes with separate base-pin connections for each electrode. Grid-no.2 operates at anode-no. 2 potential, so beam current and grid-no.1 cut-off voltage are not affected by focusing adjustment. Anode-

no. 1 takes negligible current; anode-no. 2 operates from 1000 to 6000 v.—*Tube Dep't., Radio Corp. of America, Harrison, N. J.*

Mention No. 1443 when filling out card.

Resistance-capacitance Comparator Bridge

New "Model 95OK R-C-L" is kit form of maker's comparator bridge. Unit tests resistors from 0.5 ohm to 500 megohms in four steps, and all

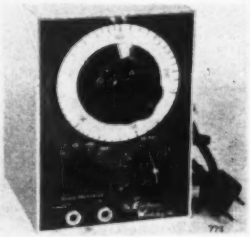


types of capacitors from 10 uuf to 5000 uf. A voltage source variable from 0-500 v. is provided; magic eye tube indicates bridge balance. Overall dimensions 10 x 8 x 4.75 in.—*Electronic Instrument Co., Inc., 276 Newport St., Brooklyn 12, N. Y.*

Mention No. 1444 when filling out card.

Audio Oscillator

New "Model 510-A" audio oscillator has frequency range of 18 cps. to 210 kc. in four decades. Unit delivers 10 v.

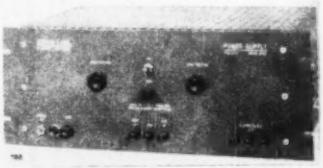


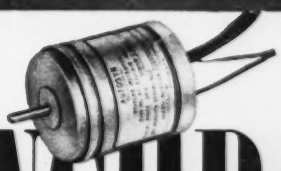
into 10,000 ohms; output is constant within 0.5 db over frequency range.—*Electronic Workshop, Inc., 351 Bleecker St., New York 14, N. Y.*

Mention No. 1445 when filling out card.

Voltage-regulated Power Supply

New "Model 131" has regulated high voltage adjustable from 100 to 325 v., delivering 0 to 150 ma. Output voltage varies 0.5 percent for line fluctuations from 105 to 125 v. and load variation





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For more than 17 years Eclipse-Pioneer has been a leader in the development of high precision synchros for aircraft, marine and industrial applications. Today, thanks to this long experience and specialization, Eclipse-Pioneer Autosyn* Synchros give you a *guaranteed* accuracy of 15 minutes (maximum) on all individual AY 200 type 400 cycle transmitters, differential generators, control transformers and resolvers. Furthermore, this phenomenal accuracy applies to *all production units* in this series. Where special applications are involved, Eclipse-Pioneer will supply Autosyn Synchros with an even *finer* degree of accuracy. And remember, when you buy from Eclipse-Pioneer, this high precision is yours at the lowest possible cost.

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Typical Performance Characteristics for one AY-201-3 Autosyn Synchro when transmitting to:

	One Control Transformer	Two Control Transformers	Three Control Transformers
INPUT			
Voltage	26-volts, single-phase	26-volts, single-phase	26-volts, single-phase
Frequency	400 cycles per second	400 cycles per second	400 cycles per second
Current	105 milliamperes	130 milliamperes	155 milliamperes
Power	0.90 watts	1.4 watts	1.9 watts
Impedance	85 + j240 ohms	80 + j180 ohms	77 + j149 ohms
OUTPUT			
Voltage max. (rotor output)	18.0 volts	15.5 volts	13.3 volts
Voltage at null	30 millivolts	20 millivolts	20 millivolts
Sensitivity	315 millivolts/degree	270 millivolts/degree	230 millivolts/degree
Voltage phase shift	18.5 degrees	24.5 degrees	28.0 degrees
System accuracy (max. possible spread)	0.5 degrees	0.5 degrees	0.5 degrees

Other E-P precision components for servo mechanism and computing equipment:

Servo motors and systems • rate generators • gyros • stabilization equipment • turbine power supplies • remote indicating-transmitting systems and special purpose electron tubes.

For detailed information, write to Dept. A

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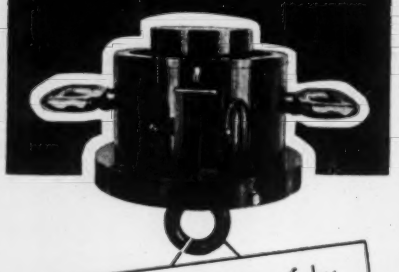
Force Measuring systems



for use in applications such as dynamometers, industrial weighing, strength of structures, jet engine thrust, and countless other force-measuring problems. Illustrated is the famous Emery Hydraulic Cell, basic unit of Emery hydraulic testing and force-measuring systems.

All components are simply constructed, but rugged; they are compact in size, extremely sensitive and accurate. Easy to mount and use. Send for complete literature and prices; also our engineers will be pleased to discuss your force-measurement problems and make recommendations.

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ACRAGAGE *Shockstop!*

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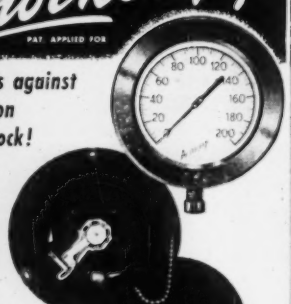

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Eliminates Snubbers— It Can't Plug—

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From less than 1 up to 10,000 psi, with various types of resistance and inductive output values, Giannini precision pressure transmitters are designed to withstand extremes of acceleration, temperature, vibration, while at the same time retaining their accuracy and their fast response characteristics. "They are standard with the Leaders." Write for booklet.

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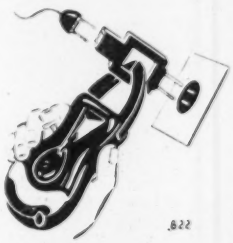
up to maximum; ripple is less than 5 mv. Regulated bias supply is adjustable from 0 to 150 v., delivers 5 ma. Regulation is 10 mv. for line fluctuation from 105 to 125 v. Unregulated a-c. supply is 6.3 v. 10 amp. center-tapped. Over-all dimensions 8.75 x 19 x 11 in.—*Kepco Laboratories, Inc.*, 149-14 41*st* Ave., *Flushing, N. Y.*

Mention No. 1446 when filling out card.

Accessories for Clamp-on Ammeter

New "Amprobe 10× Sensitizer" plugs between equipment being checked and outlet; unit has ten turns in one arm and multiplies ammeter reading ten

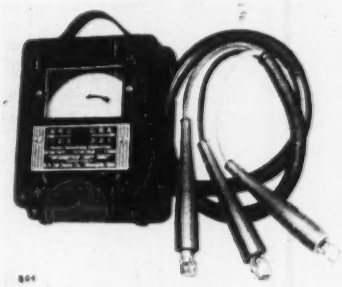


times. New "Split Plug" resembles Sensitizer, but only separates conductors where electric cord is sealed.—*Pyramid Instrument Corp.*, 49 *Howard St., New York* 13, *N. Y.*

Mention No. 1447 when filling out card.

Polyphase Sequence Indicator

New "Model 32B" phase rotation indicator operates from 50 to 600 v. 25 to 400 cps.; above 200 v., unit operates to 2000 cps. Instrument shows phase

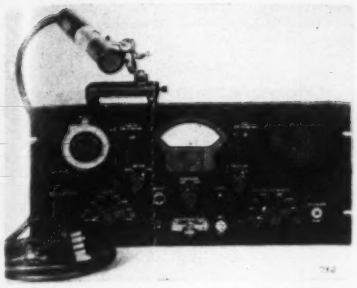


sequence by direction of disk rotation without changing connections to polyphase line. Over-all dimensions are 5.5 x 6 x 3 in., weight 3.5 lbs.—*Dep't H. H. Sell Electric Co.*, 3240 *Dakota Ave., Minneapolis* 16, *Minn.*

Mention No. 1448 when filling out card.

Counting-rate Meter for Radioactivity Measurements

New "Type 1500-B" is improved design of maker's counting-rate meter. Response speed is variable over a range of equilibrium time from 1 sec. to 3 min. Probe includes a quenching preamplifier, and is designed for hand, tripod, or bench-mount. Increased sensitivity permits use of cables up to 50 ft

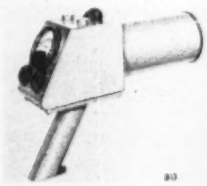


Output can operate a 5 ma. recorder.—*General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.*

Mention No. 1449 when filling out card.

Radioactivity Survey Instruments

New "Model K-352" survey instrument operates from self-contained batteries; indicator scale reads 50, 500, and 5000 milliroentgens per hr. Interior

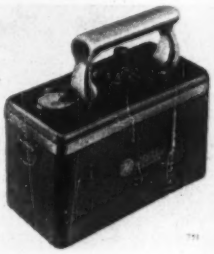


of 3 in. ion chamber, and all internal metal parts, are coated with aquadag. When 0.125-in. shield is removed, thin window permits detection of alpha, beta, and X-radiation down to 50 kv. Controls are accessible through watertight fittings.—*Kelley-Koett Instrument Co., 966-10 York St., Cincinnati 14, Ohio.*

Mention No. 1450 when filling out card.

Portable Radioactivity Survey Meter

New "Model 2581" is a battery-operated, non-discriminating, count-rate meter. Ionization chamber can detect 25 KEV beta particles and 2 MEV



alpha particles, as well as gamma and x-radiation. Indicator reads in counts per min., or milliroentgens per hr. Over-all dimensions 10 x 4.75 x 5.75 in., weight 7 lbs.—*Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago 10, Ill.*

Mention No. 1451 when filling out card.

Contact Gaging Plug

New contact gaging plug for maker's "Air-O-Limit" internal comparator gages has internal nozzles. Carbide but-

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- The logarithmic scale assures the same accuracy at *all* points on the scale.
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MODEL 300

MODEL	FREQUENCY RANGE	VOLTAGE RANGE	INPUT IMPEDANCE	ACCURACY	PRICE
300	10 to 150,000 cycles	1 millivolt to 300 volts	1.2 meg. shunted by 30 mmfds.	2% up to 100 KC 3% above 100 KC	$200.
302B Battery Operated	2 to 150,000 cycles	100 microvolts to 100 volts	2 megs. shunted by 8 mmfds. on high ranges and 15mmfds. on low ranges	3% except 5% below 5 cycles and above 100,000 cycles	$215.
304	30 cycles to 5.5 megacycles	1 millivolt to 100 volts except below 5 K C where max. range is 1 volt	1 meg. shunted by 9 mmfds. on low ranges. 4 mmfds. on highest range	3% except 5% for frequencies under 100 cycles and over 3 megacycles and for voltages over 1 volt	$225.
305	Measures peak values of pulses as short as 3 microseconds with a repetition rate as low as 20 per sec. Also measures peak values for sine waves from 10 to 150,000 cps.	1 millivolt to 1000 volts Peak to Peak	Same as Model 302B	3% on sine waves 5% on pulses	$280.
310	10 cycles to 2 megacycles	100 microvolts to 100 volts	Same as Model 302B	3% below 500 KC 5% above 500 KC	$225.

For further information, write for catalog.

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PRECISION TEN-TURN POTENTIOMETER

1. You get permanent accuracy because the resistance wire is locked in place. It is precision positioned and moulded integrally with the housing.
2. You get permanently accurate settings, smooth action and low uniform torque provided by the stainless steel, precision ground, double thread lead screw guiding the moving contact.
3. You get precise positioning of the moving contact because of the two bearings supporting the rotor assembly.
4. You get good rigid terminals because they are moulded integrally with the housing.
5. Terminals soldered to ends of resistance element before moulding. Entire resistance circuit is an integral part of the housing.
6. You get accurate setting and resetting due to anti-backlash spring in contact guide.
7. You get a fine resolution because of the 43½" length of resistance wire in the spiral element.
8. You get a resistance output directly proportional to shaft rotation within ±0.1% of the total resistance. Every potentiometer is automatically machine tested for linearity at 101 points.

LINEARITY ACCURACY ± 0.1%

Units for immediate shipment:
1,000 to 30,000 ohm range.
Special resistance values made to order.

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SOLVES INDUSTRY'S AUTOMATIC CONTROL PROBLEMS

THE ONLY 100% MERCURY SWITCH EQUIPPED CONTROLS

If you have a problem on the automatic control of pressure, temperature, liquid level, mechanical operations, etc., it will pay you to consult Mercoid's engineering staff — always at your service.

Complete Mercoid catalog sent upon request

THE MERCOID CORPORATION, 4201 BELMONT AVE., CHICAGO 41, ILL.

TEST YOUR MAGNETIC CIRCUITS

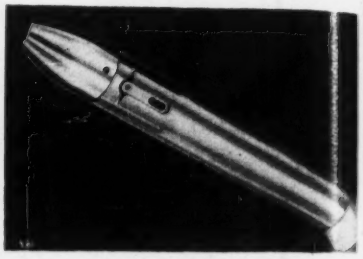
RAWSON FLUXMETER
TYPE 504

The only portable fluxmeter available which returns rapidly to zero when a single button is depressed. Simple and fast in operation. Convenient and light in weight.

Not limited to a single type of measurement. Has universal application for laboratories or production. Measures strength of magnets and electromagnets, permeability and hysteresis loops for iron and steel, total flux lines in circuit, flux lines developed in air gap, etc.

Has a mechanical clamp to protect the pivots and jewels when in transit.

RAWSON ELECTRICAL INSTRUMENT COMPANY
112 POTTER STREET, CAMBRIDGE 42, MASS.
Representatives
CHICAGO LOS ANGELES

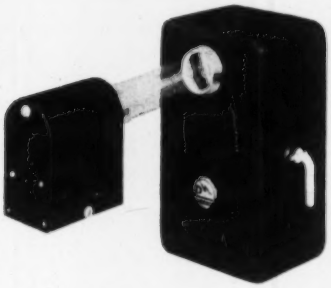


tons mounted on spring leaves are depressed by contact with work, and impede air flow from nozzles. Adjustment for set-up and wear of contact gaging buttons is provided.—*Pratt and Whitney, Div. Niles-Bement-Pond Co., West Hartford 1, Conn.*

Mention No. 1452 when filling out card.

Delayed Action Photoelectric Control

New "Set P1D" photoelectric control has an electronic delayed action timer which causes relay action only when

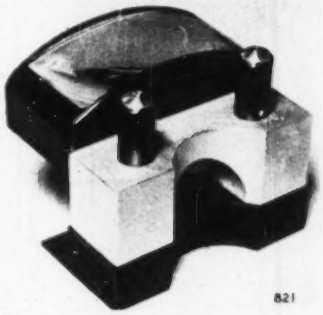


light beam is broken longer than a preset time. Unit is designed to stop a conveyor in case of jamming.—*Photoswitch, Inc., 77 Broadway, Cambridge 42, Mass.*

Mention No. 1453 when filling out card.

Machinists' Magnifying Glass

New "Magna Eye" magnifying glass mounts on height gages and vernier calipers. Improved lens covers wider



field without distortion; it can be mounted without removing thumb screw on tools. A friction adjustment holds focus when set.—*Stebar Co., 711 11 Lake St., Minneapolis 8, Minn.*

Mention No. 1454 when filling out card.

Gaging and Segregating Machine

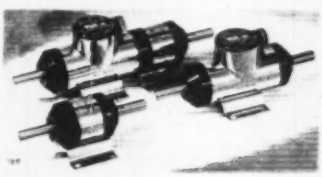
New machine automatically gages ceramic protector blocks having carbon inserts; up to 3,600 parts per hr. can be checked. Blocks are manually loaded into a magazine-type feed and a blast

of air cleans parts as they move down chute. A light panel gives visual indication of results of each gaging operation; maker's Airlectric and Electrichek heads are used as gaging mediums. Rejects are segregated into maximum and minimum chutes; parts passing all gaging stations are unloaded outside machine.— *Sheffield Corp., Dayton 1, Ohio.*

Mention No. 1455 when filling out card.

Combination Variable-speed Drives

New combinations of maker's miniature variable and fixed ratio drives provide variable output speed at any desired nominal speed, and is infinitely



adjustable over 36:1 range. Units deliver 2 lb.-in. torque. Features include ball bearing shafts, permanent lubrication, and sealed construction. Fixed ratio sections are available in extruded or hobbed gears.—*Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Mention No. 1456 when filling out card.

Adhesive Label Tape

New "Labelon" tape is made in three plies, transparent cellulose, carbon, and adhesive. It can be written on with

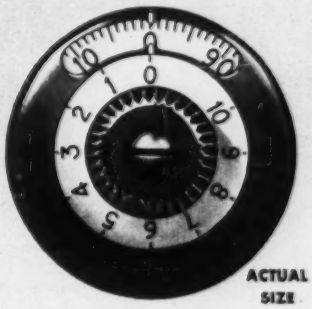
MICRODIAL
TEN TURN-COUNTING DIAL

Microdial is composed of two concentrically mounted dials . . . one for counting increments of each turn and the other for counting turns. The incremental dial has 100 equal divisions and is attached rigidly to the shaft so there is no backlash. Thus the contact position is indicated to an indexed accuracy of 1 part in 1000. Rotation is continuous in either direction. There are no stops on the Microdial assembly.

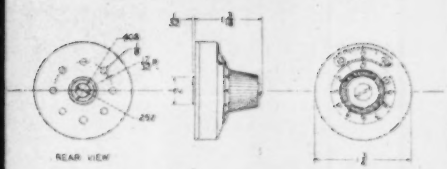
COMPACT. . . Microdial has same O.D. as Micropot . . . requires no more panel space.

CLEAR READING . . . Forced fast-reading tests showed only 1/20th as many errors with Microdial open window as with next most legible dial. Turn counter distinguishes between 0 and 10 turn readings, and accelerates to avoid confusion on readings near integral turns. Precise readings are made from larger dial with maximum separation of graduations and wide angle visibility.

CONVENIENT . . . delivered completely assembled with dials synchronized. Easily mounted in a few seconds. All dials may be locked.



ACTUAL SIZE



Microdial . . . turn-counting dial, primarily designed for use on Micropot ten turn linear potentiometers . . . use it on any multiturn device having ten turns or less.

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The NEW *Berkeley* MODEL 1600

COUNTING RATE COMPUTER

gives you these important advantages:

1. Virtually instantaneous rate of response
2. Permanent printed record of counting rate
3. Operates from either binary or decade scaler

BRIEF SPECIFICATIONS

Designed specifically for tracer applications requiring faithful response to rapid changes in counting rate, the Model 1600 will operate from any scaler that can be made to provide successive output pulses after accumulation of predetermined count. Computer then converts elapsed time between successive output pulses into average counting rate. Counting rate can be read directly on visible meter of computer.

Choice of three recording rate ranges, in combination with proper scaling factors, permits selection of conditions for optimum statistical accuracy.

When designated as Model 1600A the unit includes standard recorder which provides permanent trace of counting rate.

FOR COMPLETE SPECIFICATIONS AND OPERATING DATA PLEASE WRITE FOR BULLETINS 1600 I

Berkeley Scientific Corporation

2200 WRIGHT AVE. • RICHMOND, CALIF.

THIS FEATHERWEIGHT WILL

LICK SOLDERING FATIGUE!

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HEXACON *BANTAM*

MODEL 30H

Weight—5½ Ounces • Watts—40 or 60 • Tip Dia.—Both ⅛" and ¼" Tips Furnished with Each Iron • Price— $5.50

So light its weight is hardly noticeable. Outperforms any iron of equal size. Hatchet design makes it more comfortable and practical to use than a pencil iron. No transformer required. Write for complete catalog.

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Greatest PORTABLE of them all!

REVOLUTIONARY MODEL 400

Weight approx. 62 lbs.

AMPEX

MAGNETIC TAPE RECORDER

15,000 cps • 7½ inches per second

HALF TRACK!

- Extended range 15,000 cycle half-track recording at 7½ inches per second.
- Incredible performance that equals or exceeds most full-track 15 i.p.s. recorders.
- Saves 75% on tape by combining 132 min. of recording on a single 2400-ft. N.A.B. reel.
- Can be furnished with Single Track Heads.

Write for Complete Specifications and Control Arrangement

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San Carlos, California

STANDARD OF THE GREAT RADIO SHOWS

pencil, crayon, pen, or pointed instrument. Markings cannot be erased.—*Will Corp., Rochester 3, N. Y.*

Mention No. 1457 when filling out card.

Gage Glass

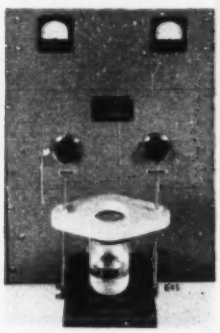
New gage glass has ball checks in head to prevent leakage in case of glass breakage. Glass is solder-sealed to bellows; connecting tubes are silver-sol-

dered into heads. One model has removable plugs at ends for cleaning glass. Glass length is 3.75 in.—*E. F. Vilter Co., 4161 N. Richards St., Milwaukee 12, Wis.*

Mention No. 1458 when filling out card.

Ultrasonic Generator

New "Model GA-1010" ultrasonic equipment includes a 1 kw. oil-filled magneto-striction generator, operating at 24 kc. Unit has an exposed vibrating



surface of 20 sq. cm., and is water cooled. Power supply operates from 115 v. 60 cps. line. Generator activates glass or metal containers 4 in. diameter.—*Massa Laboratories, Inc., 5 Fottler Road, Hingham, Mass.*

Mention No. 1459 when filling out card.

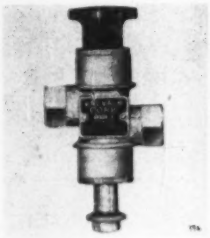
Cinemicrographic Focusing Unit

New cinemicrographic focusing unit mounts on Vickers projection microscope head, for taking motion pictures of objects on stage. Unit consists of light source, lens system, polarizers, and thermostatically controlled stage. Simultaneous photography and visual observation is one of several optional features. Movie camera is not included. —*Lovins Engineering Co., 8203 Cedar St., Silver Spring, Md.*

Mention No. 1460 when filling out card.

Manual-operation Air Valve

New air control valve has die-cast body in 0.25 and 0.375 in. pipe sizes, rated to 175 psi., 125 F. Standard pipe area opening permits unrestricted flow

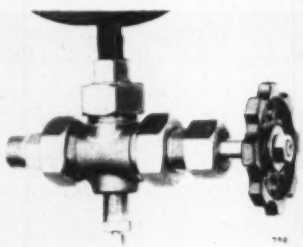


with low pressure loss, maker states. Valves with or without springs are available, assembled either normally open or normally closed to supply.—*Valvair Corp., 454 Morgan Ave., Akron 11, Ohio.*

Mention No. 1461 when filling out card.

Instrument-piping Valves

New line of instrument-piping valves features nine styles, with optional union outlet, offset, and jacketed, body. Other features include a safety shut-off;



double seating stem for repacking under pressure; regrindable and renewable seats; pressure bleed valve and test gage connection; optional O. S. & Y. and throttling stem.—*Jerguson Gage and Valve Co., 80 Fellsway, Somerville 45, Mass.*

Mention No. 1462 when filling out card.

Miniature Connectors

New "Types DPM-14 and DPM-A20" accommodate 14 and 20 contacts, 5 and 10 amp., 120 v. Contact terminals have eyelet, hook, turret and standard solder pot design. Insulation is molded melamine; socket contacts float.—*Cannon Electric, P.O. Box 75, Station A, Los Angeles 31, Calif.*

Mention No. 1463 when filling out card.

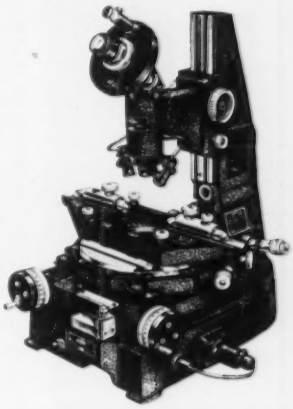
Miniature Sensitive Relay

New sensitive relay is hermetically sealed, measures 1 x 1 x 1.75 in. exclusive of terminals. Sensitivity of standard units is approximately 40 mw. Relays withstand 10 g vibration at frequencies over 60 cps.; when 2:1 margins for operate and release current are provided, relay can be used at sus-

The Gaertner

TOOLMAKERS' MICROSCOPE

For use wherever precision measurements are required in shop inspection or layout procedures.



INCH OR METRIC UNITS

Coordinate Measurements
- Left to Right ..... 100 mm or 4 inches
- Front to Rear ..... 50 mm or 2 inches

Direct Reading to .. 0.002 mm or 0.0001 inch

Angular Measurements

Stage Range	360°
Reading with Vernier	1 min.
Protractor Circle Range	360°
Reading with Vernier	1 min.
Magnification	30X
Microscope Column Tilt	±8°

- **Detects errors in cutting tools.**
- **Checks threads and thread gages.**
- **Measures critical dimensions on machine and instrument parts.**
- **Adaptable to flat work, round work, odd shapes.**

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TANK-O-METER

FOR MEASURING TANK CONTENTS ANY DISTANCE AWAY

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INSTRUMENT CO.

470 GETTY AVENUE • PATERSON, N. J.

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Another PRECISION PRODUCT

Burlington

RUNNING TIME METER

- 9999.9 hour range
- 10,000 hour automatic reset
- —55 to +55° C operating temperature.

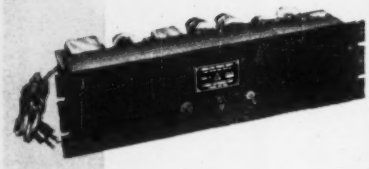
- Designed for use on AC lines where successful servicing of electronic or electrical equipment depends upon the regular servicing of such equipment based on actual operating (or idle) time. Unit has a RANGE of 9999.9 hours and resets automatically at 10,000 hours. Can be supplied for either 120 or 240 VOLTS. 60 CYCLE OPERATION and has operating temperature of —55 to +55° C.
- The Running Time Meter is housed in Burlington's attractive, black bakelite 3" square or 3½" round case.

Write Dept. H120 for further details.

BURLINGTON INSTRUMENT COMPANY
Burlington, Iowa

ELECTRONICALLY REGULATED

LABORATORY POWER SUPPLIES



STABLE • DEPENDABLE • MODERATELY PRICED

MODEL 28 STANDARD RACK MOUNTING

PANEL SIZE 5¼" × 19" WEIGHT 16 LBS.

- **INPUT:** 105 to 125 VAC, 50-60 cy
- **OUTPUT #1:** 200 to 325 Volts DC at 100 ma regulated
- **OUTPUT #2:** 6.3 Volts AC CT at 3A unregulated
- **RIPPLE OUTPUT:** Less than 10 millivolts rms

For complete information write for Bulletin N8

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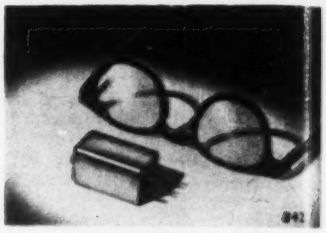
CORONA NEW YORK

Engineering Corporation established twenty-five years with experience in control field will represent manufacturer of industrial instruments in New York area requiring engineers to determine customer's requirements. Can handle inquiries but cannot solicit new business unless manufacturer furnishes leads. Box 188, Instruments Publishing Company, 921 Ridge Avenue, Pittsburgh 12, Penna.

WANTED: For new southern pulp and newsprint mill. Experienced instrument mechanics with knowledge of process and ability to maintain and repair standard instrument types. Forty hour week. $2.00 hour. Location Alabama. Write Box 189, Instruments Publishing Company, 921 Ridge Avenue, Pittsburgh 12, Penna.

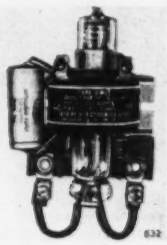


tained acceleration as high as 50 g. Contacts are available s- and d-p.d.t. —*Sigma Instruments, Inc., Boston 21, Mass.*

Mention No. 1464 when filling out card.

Mercury Relay

New "Model EM8" relay, of mercury plunger type, has load ratings to 35 amp. and 440 v. Relay employs an en-

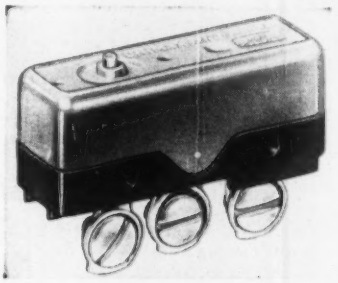


ergizing coil in a resonant circuit; external contact carries 8 ma. at 100 v.— *Ebert Electronics Corp.*, 185-09 *Jamaica Ave., Hollis 7, N. Y.*

Mention No. 1465 when filling out card.

Front-facing Terminals for Precision Switch

New "Type 3" terminals for maker switches facilitate wiring where bottom access is hampered. Screws are cadmium-

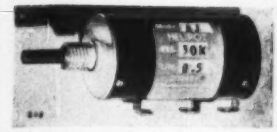


plated brass; they can be unscrewed and faced in reverse direction.—*Unimax Div., W. L. Maxson Corp.*, 460 W. *34th St., New York 1, N. Y.*

Mention No. 1466 when filling out card.

Miniature Multi-turn Voltage Divider

New "Model AJ" 10-turn voltage divider is 0.75 in. diameter and 1.375 in. long. Resistances range from 100 to 50,000 ohms, all rated 2 watts; accuracies available are 0.5 and 0.1 percent. Winding may be tapped at any point



starting torque is 0.75 in.-oz. Unit weighs 1 oz.—*Helipot Corp., S. Pasadena, Calif.*

Mention No. 1467 when filling out card.

Reusable Reagent Bottle

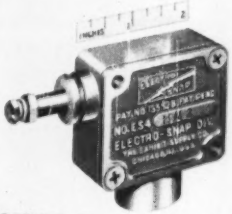
New "Aquet" bottle, made of polyethylene, contains laboratory cleaning compound; it can be refilled with any

reagent. Nozzle design provides either a full liquid stream, or a spray incorporating air.—*Emil Greiner Co., 20-26 N. Moore St., New York, N. Y.*

Mention No. 1468 when filling out card.

One-way Momentary-contact Snap Switch

New snap switch provides momentary contact on plunger's forward stroke; opens as plunger over-travels and stays



open on return stroke. S-p.d-t. switch is in plastic case, housed in aluminum die-casting.—*Electro-Snap Div., The Ezhibit Supply Co., 4218-30 W. Lake St., Chicago, Ill.*

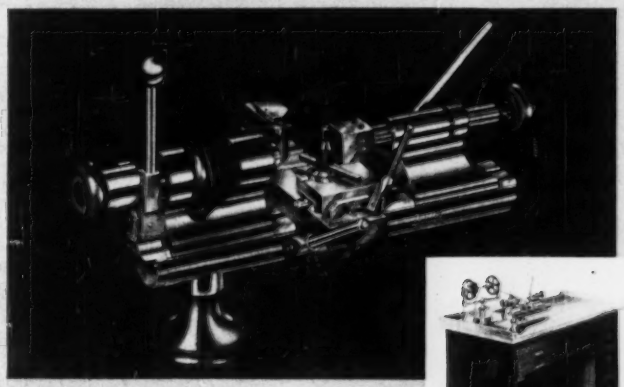
Mention No. 1469 when filling out card.

Shock and Vibration Isolator

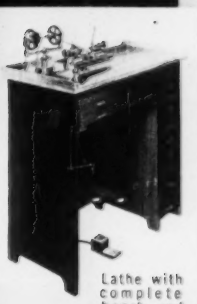
New "Series 6475 and 6695" vibration isolators are 1 in. diameter, have a loaded height of 1 in., and are air damped. Ratings range from 0.3 to 3 lbs. per mount. Center stud is tapped

HOLD A ROD .004" IN DIAMETER

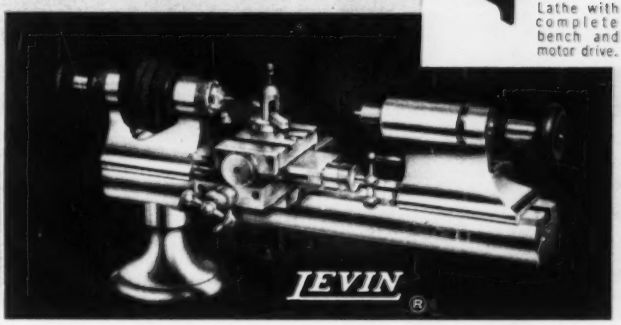
WITH COMPLETE ACCURACY



A *LEVIN* lathe makes delicate precision easy because it is designed for working with small parts. Collets from .004" to 5/16" are standard and kept in stock. Two sizes of lathes with maximum collet capacity either 3/16" or 5/16", swing 4", bed length 12". Full line of accessories for second operations, production, tool work and model making. Send for catalog.



Lathe with complete bench and motor drive.



COMPLETE CATALOG illustrates and describes full line of accessories . . . compound slide rests, grinding, milling and screw cutting attachments, cross slide, collet closer and other useful items.

LOUIS LEVIN & SON INC., 782 E. PICO BLVD., LOS ANGELES

A NEW AIR METER

FOR HIGH-ACCURACY AIR VELOCITY MEASUREMENTS

Read directly from the palm of your hand, Hastings Air Meter registers ranges from 5 to 6,000 fpm . . . weighs only 24 ounces. Powered by 110 volt or portable supply.

Write for Bulletin I-10

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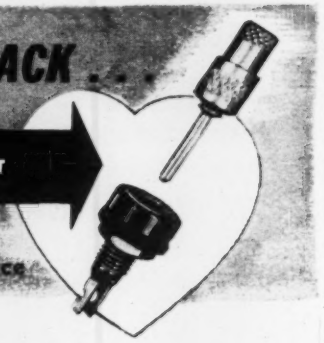
HASTINGS INSTRUMENT CO., INC.

P.O. BOX 1275 HAMPTON, VIRGINIA

HEART OF A TIP JACK . . .

IS THE SPRING CONTACT

Johnson Design, Materials Mean Longer Life, Better Service



The next time you need Tip Jacks, remember the many important advantages JOHNSON Tip Jacks offer.

First, contact in the JOHNSON Tip Jack is made along the entire length of the phone tip or test prod, and remains unchanged despite insertion of oversize tips, rough service or long use.

Second, JOHNSON uses heat treated beryllium copper contacts which remain smooth acting, have low resistance and retain high spring tension.

Although other Tip Jacks may look like those made by JOHNSON, only JOHNSON offers you heat treated beryllium copper contacts of this unique design. It's what you cannot see—the exclusive design of the contact inside the barrel—that's most important.

Third, note the large, easy-wiring terminal. Plenty of room for several wires. No solder can run inside.

Fourth, the insulated style with strong molded Plaskon heads, (illustrated) is available in ten attractive colors. They are also available without head for mounting directly in equipment, as well as in a variety of other types. In all of them JOHNSON machined parts are of highest quality, with close fitting threads and smooth finish, and may be plated to comply with any specifications.

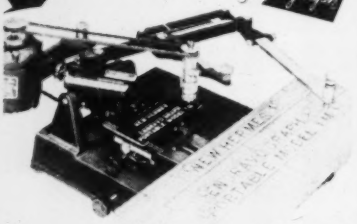
JOHNSON makes many other jacks and plugs, such as "banana" styles for military or commercial applications, as well as plug and jack board assemblies, connectors, etc. Manufacturers are invited to write for free samples and catalog information.

JOHNSON . . . a famous name in Radio!

E. F. JOHNSON CO., WASECA, MINNESOTA

SAVE TIME! do your engraving * in your OWN SHOP

WITH THE TRACER GUIDED Engravograph



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PORTABLE ENGRAVER WITH THESE FEATURES

- Engraves 15 sizes from ONE alphabet
- Covers a LARGER area than any other portable engraver
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- **Convertible into TRACER GUIDED ELECTRIC ETCHER for identifying tools and dies**

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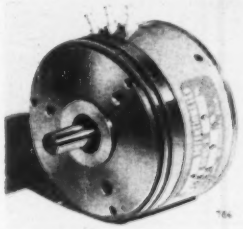
8-32, 0.25 in. deep; two mounting s yles are available—*Barry Corp., 173 Sidney St., Cambridge 39, Mass.*

Mention No. 1470 when filling out card.

Precision Voltage Divider

New "Model J" single turn precision voltage divider is equipped with ball bearings, and can be mounted in multi-



gang assemblies. Unit is 2 in. diameter, with resistances from 100 to 50,000 ohms available, and is rated at 5 watts. —*Helipot Corp., South Pasadena, Calif.*

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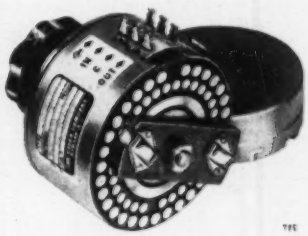
Network Attenuator

New "Series 730" network attenuator has 30 steps in 2.25 in. diameter. Unit has zero insertion loss and constant input and output impedance; available



in steps of 0.5, 1.0, 1.5, or 2.0 db, with flat frequency characteristic to 30 kc. Standard resistance accuracy is 5 percent; 0.1 percent accuracy is available. Unit has silver-alloy contacts and oilite bearings.—*Daven Co., 191 Central Ave., Newark 4, N. J.*

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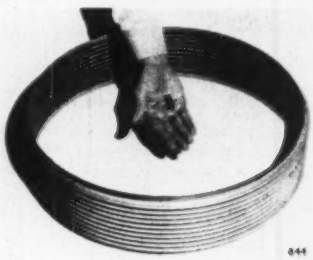
Stainless Steel Bellows

New "Hydron" line of hydraulically formed stainless steel bellows is available in sizes from 0.438 to 26.375 in. diameter. Maker states units are



suited for shaft sealing, steam traps, flexible joints, and expansion joints for large jet engines and gas turbines.—*Clifford Mfg. Co., 152 Grove St., Waltham 54, Mass.*

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Precision Resistors

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Only with wire-wound precision resistors can you obtain suitable characteristics for exacting modern circuits! Shallcross AKRA-OHMS are outstanding in such factors as stability, low temperature coefficient, low noise level, long life, and uniformity over a wide temperature range. Made to comply with JAN and other critical specifications, they are available in many types, shapes, and mounting styles. Write for Bulletin R3A

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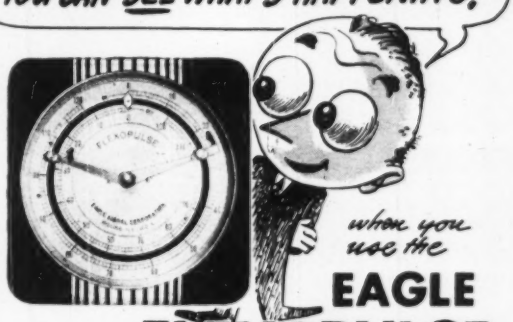

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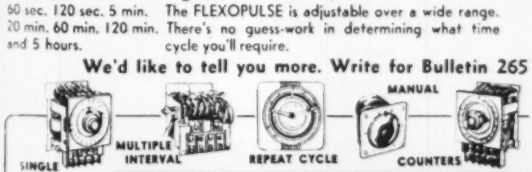

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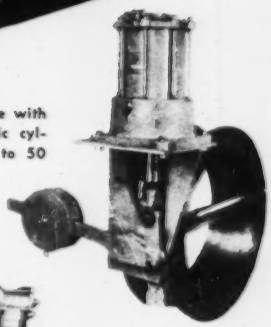
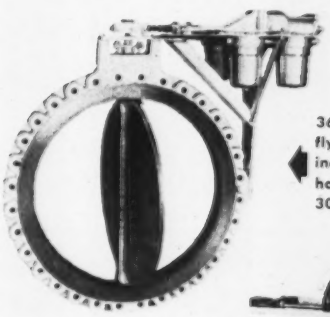
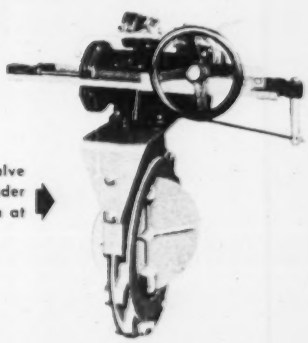
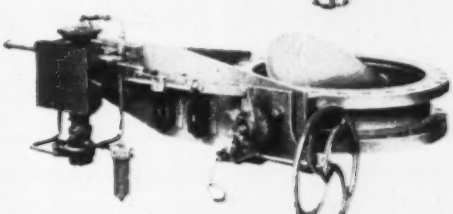




36" semi-steel wafer butterfly valve with hydraulic cylinder and limit switches for handling air at 25 p.s.i. and 300° F.



12" wafer type butterfly valve with Hagan hydraulic cylinder regulator for handling steam at 5 p.s.i. and 240° F.



30" stainless steel butterfly valve equipped with Republic Flow Meters Co. hydraulic cylinder, pilot valves, pneumatic positioner, Selsyn motor units and declutchable hand wheel; for handling saturated air at 5 to 65 p.s.i.

These are but a few examples. Rockwell Valves are made in butterfly and slide types—with any type of manual or automatic control—in pipe sizes from 1" to 84"—for normal or heavy duty pressure or temperature. Write for Catalog.

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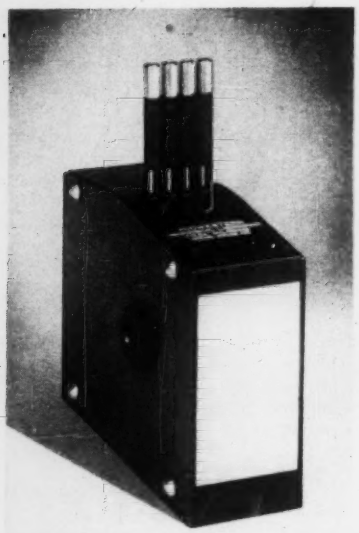

Four Trace Model Approx. Actual Size

Midwestern Model 102 Galvanometer

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- MOST SENSITIVE

Midwestern's Galvanometer Model 102 is smaller and lighter than any other now offered to industry, but is equal or superior in all mechanical and electrical details, including DC sensitivity and balance. Readily adapted to any type oscillograph, it is available in appropriate undamped frequency steps from 50 cps to 3500 cps. Precision manufacture and design have reduced the size of the 102: 4-trace—width ¾", wt 1 lb.; 18-trace width 2⅝", wt 3½ lb.; 36-trace—width 5", wt 6 lb.

As an indication of the efficiency of this new galvanometer, below are tabulated essential characteristics of two representative elements.

Type	Nominal Undamped Natural Frequency	Frequency Range Flat 5% A CPS	Undamped DC Sens. at 15° Opt. Arm MA In.	Nominal Balance Displacement Per G*
102A	100	0-60	0.008	0.03
2000	2000	0-1200	16.000	0.03

*SPECIAL BALANCE TO 0.008" PER G AT SLIGHT EXTRA COST

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INSTRUMENTS ON THE MARCH

Acoustic Measurements Made Standards

NEW YORK CITY.—Of use to all who make basic acoustic measurements are two new and one revised standard for laboratory standard pressure microphones and for earphones. All were developed under the procedure of the American Standards Association with 30 national organizations and others cooperating under the sponsorship of the Acoustical Society of America.

The first covers the reciprocity technique for Pressure Calibration of Laboratory Standard Pressure Microphones (Z24.4-1949). The second (Z24.8-1949) gives specifications for these microphones. The third (Z24.9-1949) gives a method for Coupler Calibration of Earphones.

The reciprocity technique in calibrating microphones is based on several years experience at the National Bureau of Standards, Bell Telephone Laboratories, and Harvard University. Although older methods described in Z24.4-1938 and using thermophone, pistonphone, Rayleigh disk, or other equipment are not rejected, the new method is considered the best practice consistent with the present state of the art.

The newer method yields more accurate results over a wider frequency range than older methods and is more convenient to use. Although numerous problems still exist, particularly at high audio frequencies in the free field, sufficient progress has been made to warrant revision of the standard method.

General adoption of the revision will enable agreement on calibrations by different laboratories within 0.2 decibel (±0.1 db) over the audible frequency range. Miniature crystal and condenser microphones of a variety of physical configurations may be calibrated by the reciprocity technique.

Low-temperature Work at M.I.T.

CAMBRIDGE, Mass.—The doors to the frigid world of absolute zero, 459 degrees below zero on the Fahrenheit scale, have been opened to undergraduate students for the first time in the world at the Massachusetts Institute of Technology.

Twelve senior students have completed their required undergraduate research projects by making studies of the behavior of liquid helium—helium gas so cold (452 degrees below zero) that it turns into a colorless liquid, just as steam turns into water at 212 degrees above zero.

Never before at any institution has sufficient liquid helium been available to make possible its use by such a large and relatively inexperienced research group. Financial assistance from the Signal Corps, Office of Naval Research, and Air Material Command, through contracts with M.I.T.'s Research Laboratory of Electronics, made the program possible for the twelve students majoring in physics.

Dr. Melvin A. Herlin, assistant professor of physics, believes that the students' work constitutes an important part of the low-temperature research program underway at M.I.T., with the cooperation of the Research Laboratory of Electronics and the departments of physics and mechanical engineering.

That the work was possible, he says, marks a real achievement in the mass production of low-temperature materials. Robert P. Cavileer of the M.I.T. research staff, whose responsibility it is to supply liquid helium to the many research activities which use it, has probably handled more of the elusive stuff than anyone else in the world.

Liquid helium is important because it liquefies at a lower temperature than any other gas—and thus is the lowest-temperature material available. Liquid helium is considerably colder than the liquid form of such common gases as nitrogen, oxygen, or air.

As such, it shows some phenomena which are among the top puzzles of physics today. At about two degrees below its boiling point, liquid helium begins to act like no other material known and enters what seems to be a "fourth state of matter."

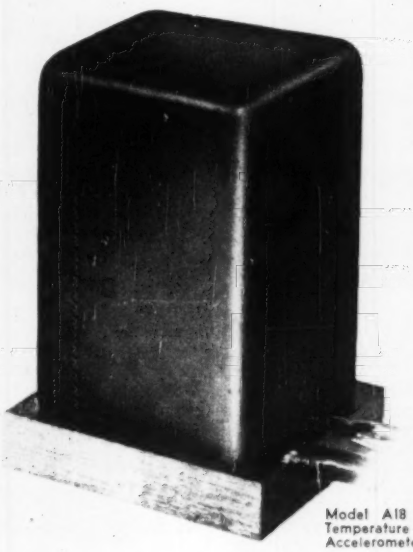
It climbs up the sides of its containers; no dish can float in it. It conducts a pulse of heat in much the same way that ordinary liquids conduct a wave of sound.

Spectrophotometric Equipment Installed at Princeton

PRINCETON, N. J.—Princeton University has become one of the few, if not the only institution in the country, to teach spectrophotometric methods of chemical analysis at the under-graduate level. The recent installation of special equipment has permitted the courses in the rapid identification of materials to be given by the department of chemistry at Princeton.

A complete spectrophotometric laboratory has been equipped for the use of undergraduate chemists. This equipment is used for rapid identification and quantitative analysis of both organic and inorganic substances. The equipment has two principal advantages over older methods of identifying materials: it does the analysis in much faster time and also identifies materials that cannot otherwise be identified. The laboratory is under the direction of Dr. Nathaniel H. Furman, Moore Professor of Chemistry. [From the New York *Herald Tribune*, Nov. 19, 1950.]

STATHAM TEMPERATURE CONTROLLED ACCELEROMETERS



Model A18
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Statham temperature controlled accelerometers are now offered to eliminate the variation in damping during the measurement of acceleration where temperature extremes are encountered over the ambient temperature range—65° F. to +150° F.

Temperature controlled accelerometers are provided with a heater, thermostat, and insulating jacket. The damping fluid temperature is held at approximately +150° F. The heater voltage is nominally 24 volts, with a peak power input of 20 to 30 watts. As illustrated, the heater leads are brought out through a cable independently of the signal leads.

Statham temperature controlled accelerometers are available in two models: The Model A 17 temperature controlled instrument is the counterpart of the Statham Model C accelerometer, while the Model A 18 temperature controlled accelerometer corresponds to the Statham Model A8 accelerometer.

Additional particulars will be supplied upon request

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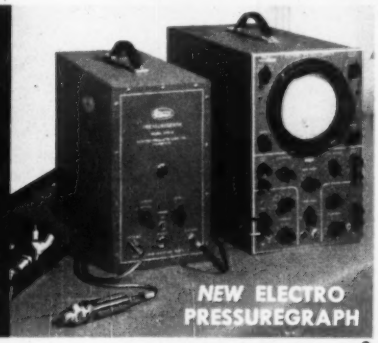

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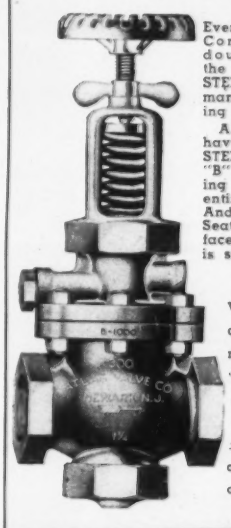

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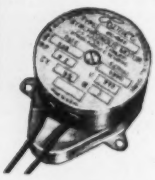

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VALVE PLUGS

Continued from page 1267

The reversal of direction of stem force which can occur as the valve is opened reverses the differential pressure in the springless motor. In the simple motor illustrated in the diagrams, the unsupported portion of the diaphragm must reverse position, giving the effect of lost motion and possible instability. This is overcome by using two diaphragms separated and vented in between—a material complication in design. In single-seated valves where there is no reversal in the force direction, the double diaphragm construction is unnecessary.

Acknowledgment: The author wishes to express his appreciation to Paul Wing, Jr. of the Mason-Neilan Engineering Department for his invaluable aid in supervision of the experimental work and assistance in the preparation of this paper.

OIL LABORATORY

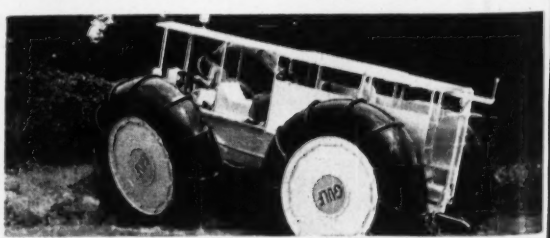
Continued from page 1247

values on a single ring. That may be all right for research but it is not fast enough for inspection in the shop. The test would cost more than could be afforded. We designed an instrument consisting of a series of air elements; 18 cylinders placed around a cast iron ring which represents the cylinder. The piston ring to be tested is slipped into place opposite these piston elements. They are each fed by a disk orifice at 20-lb. air pressure, and there is a little gas engine valve with a knife-edge seat which kicks the ring off the wall of the cylinder. As soon as it does that it opens up the second orifice and drops the pressure. The pressure between the two orifices indicates the load on the ring. Some of the results were quite interesting. Rings that were going into aviation engines, the expensive rings that were supposed to be the best, had a variation of six to one in pressure around the ring. Of course the ring is going to give trouble if that is the case. Everybody assumed the ring was uniform, but nobody ever found out how variable it really was.

We tested some of the older designs of piston ring testers of the mechanical drop-out type and found that not even the best of them on the market would check within 30 percent. When you get a polar diagram of the loads on the ring you ought to be able to make sine components, split the diagram and the sine components ought to balance because the ring is floating on the points. We found that by taking chrome plated rings and lapping them so they were a good firm surface, they are able to repeat within one-half percent. With this device a reading can be taken on a ring in half a minute and the figures written down, or it may be photographed in 15 seconds. It is also good enough for production inspection; in fact about six of these machines are now being used by the piston ring companies.

We often want to know what the temperatures are in the piston at the ring and for many years everybody, particularly General Motors who had done the most work on it, was using contacts from thermocouple rings which came down to tap the contactor. The couples could not be kept going for more than fifteen minutes because no matter what spring is used, it will fatigue under those conditions and break off. This time we got wise and just slid the contacts past each other, and that works.

That is a rough picture of some of the instruments we must deal with in the oil laboratory. It might even be said that the "Marsh Buggy" was an instrument, in a way because we wanted it to take geophysical instruments into the marshes. Anything is liable to pop up in the way of instruments, but you will have recognized that many of the



Gulf "Marsh Buggy"

Operation and Care of Circular-scale Instruments

By

JAMES SPENCER

For 20 years in charge of Instrument and Relay Department, Meter Div., Westinghouse Electric Corp.

CONTENTS

EDITOR'S FOREWORD

AUTHOR'S PREFACE

CHAPTER I—ESSENTIAL TOOLS

CHAPTER II—D-C. INSTRUMENTS

Dismounting and Reassembling. KX-124 Instruments, DB-12 Instruments, Test and Inspection, Principles of Operation, Maintenance, Connections.

TROUBLE CHART FOR D-C INSTRUMENTS

CHAPTER III—A-C. AMMETERS AND VOLTMETERS

Principles of Operation, Construction, Dismantling KA-24 Instrument, Reassembling. Dismantling DB-12 Instrument, Test and Inspection, Internal and External Connections, Maintenance.

CHAPTER IV—ELECTRODYNAMIC TYPE INSTRUMENTS

WATTMETERS, Construction, The KF-24 Wattmeter, The AB-12 Wattmeters, Connections, Principle of Operating, Inspection and Calibration, Single-phase Wattmeter, Poly-phase Wattmeter, Maintenance.

FREQUENCY METERS, Construction, The KF-24 Instrument, The AB-12 Instrument, Principles of Operation, Test and Inspection, Maintenance.

CHAPTER V—POWER FACTOR METERS AND SYNCHROSCOPES

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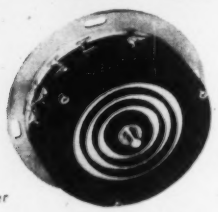

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"Two potentiometers in one" most aptly describes the Fairchild Differential Computing Potentiometer. This versatile unit makes it possible to combine two input variables and obtain an output that is proportional to their sum or difference.

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Suggested applications include servomechanisms, instrument controls, and computing and analyzing instruments. The D-C-P will directly replace two single potentiometers when one is used for compensation or correction purposes. For more data, write to Fairchild Camera and Instrument Corporation, 88-06 Van Wyck Boulevard, Jamaica 1, N. Y. Dept 140-12B.

FAIRCHILD
PRECISION POTENTIOMETERS

elements in industrial instruments are in these tric devices as well.

We hear a good deal about electronics these days. It isn't *necessary* to do it electronically if it can be done mechanically, because the mechanical setup will usually be more rugged and perhaps more reliable. Many things cannot be done any other way than electronically, and of course electronic devices should be used in these cases. Use the best device—old or new—for the job.

NEW CONCEPT *Continued from page 125*

to be widened excessively in order to prevent overpeaking and this in turn would allow the temperature to deviate too much with load changes. The facts are that the sensitivity must be lowered excessively, but it can be shown that this new controller can produce exactly the same response to load changes as the more conventional controllers *with the sensitivity dial set at a considerably lower value.* Furthermore, there are new values of the derivative time and the reset rate which must be used if the full benefits of the proposed control circuit are to be obtained. While work is under way to illustrate this by means of analogs and actual field tests, the easiest approach to the problem is through mathematics.

Now, without developing the equation in detail, the controller in Fig. 6 can be described by

$$(6)\quad \frac{dp}{dt} = n(1+RT')\,S'\left[\frac{R'}{1+RT'}(x-x_0) + \frac{dx}{dt} + \frac{T'}{1+R'T'}\frac{d^2x}{dt^2}\right]$$

It will be noted that in equation (4) $\overline{S}$, $\overline{R}$, and $\overline{T}$ have been used to denote the instrument adjustments in a non-interacting controller. In equation (5) R, S, and T have been used to denote the controller adjustments in our conventional controller. In equation (6) R', S', and T' are the adjustments in the proposed new controller while "n" is the gain in the reset relay. Note that this gain factor "n" multiplies the proportional response in the same way that the sensitivity (S) does.

Now, if the controller, the conventional controller, and the non-interacting controller are to perform in an identical manner in response to load changes, the coefficients of each term in the equation must be equal. In other words,

	Response	Actual Coefficients	Coefficients in Conventional Controller	Coefficients in Proposed Controller
(7)	Proportional	$\overline{S} =$	$\frac{1+RT}{1-RT}\,S = n\,(1+R'T')\,S'$	
(8)	Reset	$\overline{SR} =$	$\frac{R}{1-RT}\,S = n\,S'\,R'$	
(9)	Derivative	$\overline{ST} =$	$\frac{T}{1-RT}\,S = n\,S'\,T'$	

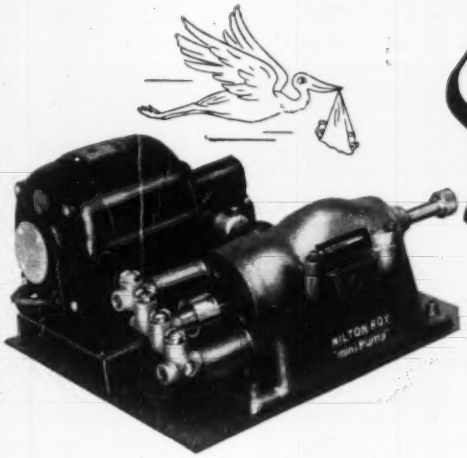
Since we are interested in the dial readings on the new instrument in terms of the dial readings on the old instrument rather than in terms of the corresponding readings on the non-interacting controller, these three equations may be solved:

$$(10)\quad nS' = \frac{S}{1-RT},\ R' = R \text{ and } T' = T$$

and

$$(11)\quad nS' = \frac{RTS}{1-RT}\quad R' = \frac{1}{T} \text{ and } T' = \frac{1}{R}$$

Now, equations (10) and (11) can tell us a great deal about this new controller. For example, if a conventional controller has been properly set up and adjusted to the process the values of S, R, and T are known. It has been well established that the product of RT cannot equal 1, and as a matter of fact, Ziegler & Nichols indicate that this product should be in the neighborhood of 0.25. If this is the case, the product of the apparent sensitivity and the



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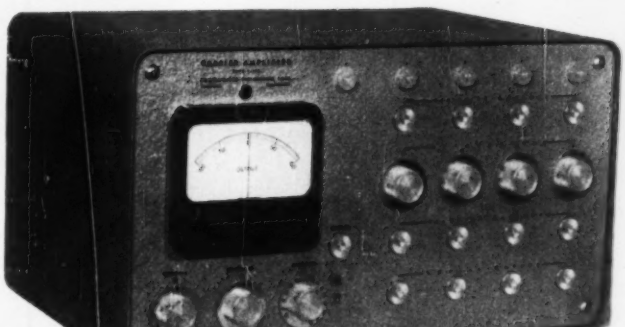

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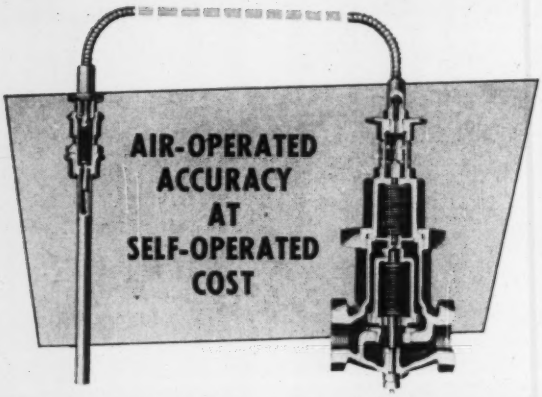

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gains (nS′) in the new controller must be one-third greater than the sensitivity reading on the old controller, according to equation 10. With this particular sensitivity, the reset rate (R′) and the derivative time (T′) readings are identical with those on the conventional controller. However, equation (11) proposes another solution in the adjustment of sensitivity, reset rate, and derivative time. Again, following Ziegler & Nichols' recommendations, when RT = 0.25 from equation (11) the apparent sensitivity of the proposed controller can be one-third of the reading on the conventional controller while the new reset rate is the reciprocal of the former derivative time, and the new derivative time is the reciprocal of the former reset rate. Note that the product of the new reset rate and the derivative time settings (R′ T′) is 4.

This second solution is extremely interesting for it points out that in this new controller the sensitivity setting (the dial reading) can be lowered to one-third of its previous value and yet the actual sensitivity of the controller will be unchanged, provided that the reset rate and the derivative time dials are adjusted in accordance with the recommendations of equation (11). In other words, the actual sensitivity of this controller in the second set of adjustments can be identical with the sensitivity of a corresponding conventional controller, and yet the dial reading can be considerably below the values previously established. The importance of this suggestion is not that there are two methods of obtaining the same results with a controller, but that this second method with its broader throttling range (lower sensitivity) enables the controller to prevent overpeaking during start-up conditions on difficult applications.

In adjusting a controller in the conventional manner, the sensitivity would be lowered until stability was obtained. The reset and derivative functions would then be cut-in and in all probability the series of settings suggested by equation (10) would result. Under these conditions, it is quite likely that when the process is started up, overpeaking would still occur although it would be less than with the conventional controller since the first proportional band has not been shifted above the control point. Now, by lowering the sensitivity of this controller to one-fourth of this value and setting the reset rate and the derivative time in acordance with equation (11) at considerably higher values, identical performance following load changes can be obtained, *and at the same time the controller will not overpeak on start-up.*

Conclusions

In review, it is our feeling that a good solution has been offered to the old problem of poor start-up characteristics when automatic reset must be used. Although this control system offers great advantages on batch and semi-continuous operations where start-up may occupy the greatest portion of the processing time, the system also has merit on continuous operation.

One factor which must be remembered in using this new system is that if the control problem is approached in the conventional manner, the full benefits of the control system may not be realized. Although it is true that the overpeaking will be less than with the conventional controller, particularly if it does not have the derivative function, it is also true that the overpeaking may not be entirely eliminated. The elimination may always be accomplished by lowering the controller sensitivity and at the same time increasing the reset rate and the derivative time. Finally, there are many values of S′, R′ and T′ which lie between the values mentioned. These values will produce stable control but the performance following a load change will differ. Still, this performance may be entirely satisfactory, while the performance of the controller on start-up may be considerably improved. It is suggested that these values of S′, R′ and T′ be more fully investigated on actual processes and on analogs to determine the values which produce the best start-up characteristics. As a suggested criterion, the controller performance is best on start-up when the control point is reached with a minimum delay without overpeaking. On many applications, it would appear that this criterion should be used to adjust the controller rather than the performance following a sudden load change.

INSTRUMENT SOCIETY OF AMERICA

Journal

THE SECRETARY'S PAGE

Richard Rimbach

Report on the Employment Register

The Employment Register at the Fifth National Instrument Conference and Exhibit at Buffalo, Sept. 18-22, 1950, was operated by John D. Duthie, Chairman, Employment Committee, Niagara Frontier Section, and Mrs. Clair Hull, Technical Librarian, Assistant to John D. Duthie for the Employment Register.

It was not possible to determine the number of individuals who surveyed the open positions posted on the bulletin board but our estimate would be approximately 300. Many of these took notes on the open positions and the names and addresses of the prospective employers for contact by mail after returning home. No reports were received from prospective employers or applicants on the outcome of interviews and it is assumed that the many factors involved precluded spot hiring. It is to be hoped that the prospective employers or applicants will later report to the National Office on the outcome of the interviews.

Positions Open	At Opening Sept. 18	At Closing Sept. 22
Positions posted on bulletin board by prospective employers for general survey:	12	75
Prospect employers who examined files of applicants for qualified men:		42
Applicants		
Instrument Engineers applications for positions on file:	11	40
Instrument Mechanics applications for positions on file:	6	50
Interviews		
Interviews arranged between prospective employers and applicants:		30

I believe the services of the Employment Register may be improved so as to expedite the handling of and avoid delay for the prospective employers and applicants. Toward this end the following suggestions are made for study for

REGISTER *Continued on page 1297*

Instrument Mechanics Maintenance Clinic

One of the functions to be sponsored by the Instrument Society of America at its Sixth Annual Conference and Exhibit in Houston during September of 1951 is a Mechanics Maintenance Clinic held just prior to the main Conference.

C. R. MILLER

At the October 10, 1950 meeting of the Houston ISA '51 Convention Committee in the Houston Chamber of Commerce Board Conference Room, Mr. C. R. Miller of the General Tire and Rubber Company, Baytown, Texas, was appointed as Local Chairman of the Instrument Mechanics Maintenance Clinic Committee. Mr. Miller will serve as liaison man with the ISA National Committee, which handles this function, and will also head up all the local work in connection with the Clinic. This will be the third of such a group of meetings; Clinics have been held in St. Louis in 1949 and in Buffalo in 1950.

In order to best serve those who expect to attend the Maintenance Clinic in Houston in '51, it is most desirable that all ideas concerning these meetings be sent to the Local Chairman for his

CLINIC *Continued on page 1297*

Section Secretaries, Meeting Data and Programs

AKRON
Fred Appel, 932 Columbia Ct., Barberton, Ohio. Tel: SH 3440
Fourth Tuesday, Meeting at 7:30 P. M., Akron Y.W.C.A.
Jan. 23, "Principles of Automatic Control," ISA color and sound film by G. F. Akins, J. Kowalski, Eastman Kodak Co.

ALBUQUERQUE
E. J. Burda, Sandia Corp., P. O. Box 5800, Albuquerque, N. Mex.
First Monday, Meeting at 8:00 P.M., Science Lecture Hall, Univ. of N. M.

ARUBA
K. H. Walker, P. O. Box 389, c/o Lago Oil & Transport Co., Ltd., Aruba, N.W.I.
First Tuesday, Meeting at 7:15 P. M., Engr's Club.

ATLANTA
H. Kockritz, Fischer & Porter Co., 84 Peachtree St., Atlanta, Ga. Tel: CY 1269
Fourth Monday, Meeting at 7:45 P.M., Ga. Institute of Technology.

BALTIMORE
W. A. Dickinson, 2716 Dunbrook Ct., Baltimore 22, Md. Tel. Dundalk 2272J
Second Friday, Meeting at 8:00 P.M., Engr's. Club of Baltimore.

BATON ROUGE
John Q. Bass, 1517 Longwood Dr., Baton Rouge, La. Tel: 3-0283
Meeting monthly, no definite time, L.S.U. Physics Bldg.

BOSTON
Stephen E. Lord, 60 Braintree Ave., Quincy 69, Mass. Tel: MA 9-1066
Last Wednesday, Dinner at 6:30 P. M., Meeting at 7:00 P.M., 99 Club, 99 State St.

CALIFORNIA
D. C. Duncan, Helipot Corp., 916 Meridian Ave., S. Pasadena, Calif. Tel: SY 4-8439
Second Wednesday, Dinner at 6:30 P. M. Meeting at 8:00 P.M., Carolina Dines.

CENTRAL ILLINOIS
Thomas A. Carroll, 721 Hurlburt St., Peoria 6, Ill. Tel.: Peoria 4-8909
First Wednesday, Dinner at 6:30 P.M., Meeting at 7:30 P.M.

CENTRAL INDIANA
Richard F. Rieman, 3550 Euclid St., Indianapolis, Ind. Tel. CH 7462
First Tuesday, Meeting at 7:30 P. M.

CENTRAL NEW YORK
Karl W. Robertson, Minneapolis-Honeywell Reg. Co., 121 W. Onondaga St., Syracuse, New York.

CHARLESTON
Clayton A. Williams, 303 E. 9th St., Belle, W. Va. Tel: 927871
First Monday, Dinner at 6:15 P.M., Meeting at 8:00 P.M., Kanawha Hotel.

CHICAGO
Floyd E. Ertsman, Rm. 1420 Fisher Bldg., 343 S. Dearborn St., Chicago 4, Ill. Tel: WE 9-0686
First Monday, Dinner at 6:30 P. M., Meeting at 8:00 P. M., Shoreland Hotel.
Jan. 8, "Measurement of Finishes," Dr. E. J. Abbott, Physicist Research Co.
Feb. 5, "Spectrophotometry—Mass Spectrograph," Dr. Grubb, Std. Oil Co., Indiana.

CHINA LAKE
A. H. Staud, 1004 Michelson Lab., USNOTS, China Lake, Calif. Tel: 77882
Fourth Thursday, Meeting at 8:00 P.M., Michelson Lab, USNOTS.

CINCINNATI
L. W. Greene, 181 Market St., Aurora, Ind.
Second Monday, Meeting at 8:00 P.M., Eng'r. Society Hqs.

CLEVELAND
A. E. Ehrke, 1732 East 291st St., Wickliffe, Ohio. Tel: WI 3-1036
Fourth Wednesday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Cleveland Eng'r. Society, E. 19th St.

COLUMBUS
W. C. Myers, c/o Battelle Memorial Institute, 505 King Ave., Columbus, Ohio. Tel: UN 3191, Ex. 248
Third Thursday, Meeting at 8:00 P.M., Battelle Auditorium

CUMBERLAND
Clyde Babst, 225 Cecilia St., Cumberland, Md. Tel: 583-W
Tuesday after Fourth Monday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Algonquin Hotel.

DETROIT
A. W. Brueckner, 5556 S. Clarendon Ave., Detroit 4, Mich. Tel: TYler 6-9511.
Third Tuesday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Rackham Bldg.
Jan. 16, Subject: Measurement of Radioactivity from Atomic Blasts.
Feb. 20, "The Technique of High Speed Photography," W. G. Moline, Ford Motor Co.

EASTERN NEW YORK
W. R. McKegg, c/o Gen. Engrg. & Consulting Lab., G. E. Co., Schenectady, N. Y.
First Tuesday, Dinner at 6:30 P.M., Meeting at 8:00 P.M.

GULF COAST
W. N. Sloan, E. I. Du Pont de Nemours & Co., Orange, Texas. Tel: 8411 Ext. 444
Third Tuesday. Meeting at 7:30 P.M., Lamar College, Beaumont, Texas.

HOUSTON
I. K. Farley, 2123 Travis St., Houston, Texas, Tel: Charter 2511.
Last Monday, Meeting at 8:00 P.M., Engineers Club.

KANSAS CITY
L. E. Oberhelman, Standard Oil Co., Sugar Creek, Mo. Tel: MU 1227
First Tuesday, Meeting at 7:30 P.M., Univ. of Kansas City.
Jan. 9, "Nucleonics in Industry," W. J. Ladniak, Carbide & Carbon Chemicals.
Feb. 6, "Gas Analysis Instrumentation," N. W. Hartz, Mine Safety Appliances Co.

LOUISVILLE
H. C. Scherffius, 980 Palatka Rd., Louisville 8, Ky. Tel: Franklin 1265
Fourth Tuesday, Meeting at 8:00 P.M., Seagram Auditorium.

MONTREAL
S. J. Mizuhara, 1075 Allard, Verdun, Quebec, Canada. Tel: TR 3252
Last Monday, Meeting at 8:00 P.M. Mechanics' Institute.

NEW JERSEY
Fred L. Crabbe, Malcolm W. Black & Co., Inc., 41 East 42nd St., New York 17, N. Y. Tel: Vanderbilt 6-2960.
First Tuesday, Dinner at 6:00 P. M. Meeting at 8:00 P.M., Essex House, Newark.
Jan. 9, "The Need for Instruments and Invention in Industry," E. G. Bailey, Babcock & Wilcox Co.
Feb. 6, "Radioactive Measurement Apparatus," W. C. Nusbaum, Tracer Lab.

NEW ORLEANS
W. H. Haney, 2927 Music St., New Orleans 22, La.
No Regular Date, Meeting at 8:00 P.M.

NEW YORK
F. B. Leslie, 8856 Commonwealth Blvd., Bellerose 6, N. Y. Tel: FI 7-0645
Last Monday, Dinner at 6:00 P.M., Meeting at 7:45 P.M., Henry Hudson Hotel.
Jan. 26, 27, Annual Regional Conference, Hotel New Yorker. Four Sessions on Modern Process Controllers. Meetings from 9:00 A.M. to 5:00 P.M. Dinner on Friday Evening.

NIAGARA FRONTIER
Mrs. James L. Martin, 697 Potomac Ave., Buffalo 22, N. Y. Tel: GR 1450
Fourth Monday, Dinner at 6:00 P.M., Meeting at 8:00 P.M., N. Y. State Inst. of Arts and Sciences, Buffalo.
Jan. 22, "Automatic Control for Steam Boilers," P. S. Dickey, Bailey Meter Co.

NORTH TEXAS
R. E. Byers, 6000 Lemmon Ave., Dallas 9, Texas

NORTHERN CALIFORNIA
S. D. Stillson, 1324 Everett St., El Cerrito, Calif. Tel. Becon 2-7139
Third Monday, Meeting at 8:00 P.M., East Bay Area.
Dec. 18, Spenger's Grotto, Berkeley, "Pressure Regulation & Regulators," T. E. Gannon, Grove Reg. Co.
Jan. 15, East Bay, "Radiation Measurements," Hugh Rodman, G. M. Cooke.
Feb. 19, San Fran., "Temperature Measurements," Herman Held, Weston Elec.

NORTHERN INDIANA
J. Baum Beckman, 547 N. Waller Ave., Chicago 44, Ill. Tel: ES 8-7776
First Wednesday, Meeting at 7:30 P.M., Whiting Community Center, Whiting, Ind.

OAK RIDGE
John H. Clark, 230 Canton Hall, Oak Ridge, Tenn. Tel: 5-9142
First Wednesday, Dinner at 6:30 P.M., Meeting at 7:30 P.M., Oak Terrace.

ONTARIO
John W. Huether, 311 Southerland Dr., Leaside, Ontario, Canada. Tel: HU-7114
Meeting at 8:00 P.M.
Third Thursday, Meeting at 8:00 P.M. Friendship Hall, College St. United Church, Toronto

PANHANDLE
R. E. Harris, 228 Maya Bldg., Amarillo, Texas. Tel.: 31434.
Third Tuesday, Meeting at 8:00 P.M.

PHILADELPHIA
C. W. Wood, 6908 Market St., Upper Darby, Pa. Tel: Clearbrook 9-3959
Third Wednesday, Meeting at 8:00 P.M. Bellevue Stratford Hotel.

PITTSBURGH
Miss Louise Suckfield, P.O. Box 2038, Pittsburgh 30, Pa. Tel: HI 1-1800
Fourth Monday, meeting jointly with the Technical Committee on Inspection and Gaging. Dinner at 6:30 P.M., Meetings at 8:00 P.M., Roosevelt Hotel.
Dec. 18, Christmas Party.
Jan. 22, "Instrumentation for the Operating Engineer," J. S. Leslie, Leslie Co., Inspection Committee Speaker: James Mulligan, Mesta Machine Co.

PRESQUE ISLE
Edwin P. Schuwerk, 445½ Halley St., L. P. Erie, Pa. Tel: 2-3349
Fourth Tuesday, Meeting at 8:00 P.M., G. E. Community Center, East Lake Rd., Erie, Pa.

RICHLAND
R. A. Nederhood, 2003 Trippe, Richland, Washington. Tel. 5-4442
Second Wednesday, Meeting at 7:30 P.M. American Legion Hall.

ROCHESTER
R. C. Schwarz, Jr., 1201 Granite Bldg., Rochester 4, N. Y. Tel: Monroe 4610R
Fourth Tuesday, Meeting at 8:00 P.M., Univ. of Rochester, Physics Lecture Hall.

SARNIA
J. J. Connors, 272 Elgin St., Sarnia, Ontario, Canada. Tel: 1970 W
Second Friday, Meeting at 8:00 P.M., Moose Hall.

SOUTH BEND
Sam M. Rouse, 436 Moccasin Ave., Buchanan, Mich. Tel: 678
First Thursday. Meeting at 8:00 P.M., Engineers Club, Hotel La Salle, South Bend.

SOUTH MICHIGAN
W. J. Sprau, 2509 S. Rose St., Kalamazoo, Mich. Tel: 4-7012.
Fourth Wednesday, Dinner at 8:30 P.M. Meeting at 8:00 P.M., Chicken Charlie's, Kalamazoo.

SOUTH TEXAS
H. C. Givens, La Gloria Corp., P.O. 637, Falfurrias, Texas. Tel: 122-W
First Thursday. Meeting at 7:30 P.M., Garrett Aircraft Instrument School.

ST. LOUIS
W. G. Lee, 4710 Delor St., St. Louis 16, Mo. Tel: FL 8816
First Wednesday, Meeting at 8:00 P.M., Engineer's Club of St. Louis.
Jan. 10, "Nucleonics in Industry," W. J. Ladniak, Carbide & Carbon Chemicals.
Feb. 7, "Gas Analysis Instrumentation," N. W. Hartz, Mine Safety Appliances Co.

TOLEDO
Morris L. Conner, 925½ Sherman St., Toledo, Ohio. Tel: MA 9403
Third Tuesday, Meeting at 8:00 P. M., Service Bldg., Toledo Edison Co.

TENNESSEE
N. M. Taylor, 16 Edgewood, Kingsport, Tenn. Tel: 3338J
No definite night, Dinner at 6:45 P.M., Meeting at 8:00 P.M., Hall's Dining Rm., Bristol Hwy., Kingsport.

TULSA
J. J. Fox, Phillips Petroleum Co., Phillips Bldg., Bartlesville, Okla. Tel: 6600 Ext. 501.
First Monday, Meeting at 7:30 P.M., Engineering Bldg., Tulsa Univ.
Jan. 8, "Nucleonics in Industry," W. J. Ladniak, Carbide & Carbon Chemicals Co.
Feb. 5, "Gas Anlysis Instrumentation," N. W. Hartz, Mine Safety Appliances Co.

TWIN CITIES
Alden Hine, c/o Pinkney & Hine, 552 Plymouth Bldg., Minneapolis 3, Minn. Tel: Lincoln 0523.
Fourth Tuesday, Dinner at 6:30 P.M. Coffman Memorial Union, U. of Minn.

WASHINGTON
Raymond E. Miller, 20-224 Naval Ord. Lab. White Oak, Md. Tel: JU 7-6742
Third Monday, Meeting at 8:00 P.M., P. E. P. Co. Auditorium.

WAYNE COUNTY
Robert Karr, 2455 Biddle Ave., Wyandotte, Michigan. Tel. 0167J
Third Monday, Meeting at 8:00 P.M., Larson's Cafe, Lincoln Park, Mich.

WILMINGTON
Dean Valentine, 34 N. Hill Drive, West Chester, Pa. Tel: 0293W
Third Tuesday, Meeting at 8:00 P.M. Harlan Public School, Wilm.

CLINIC *Continued from page* 1295

guidance as soon as possible. Preferences are desired in regard to the following matters:

1. Should the equipment studied and discussed be primarily new equipment, or is it desirable to include maintenance practices regarding older types of equipment?

2. Is it desirable to discuss specific pieces of equipment in detail or to cover general types of equipment in less detail?

3. Is it preferable that the instructors be primarily manufacturers' representatives or primarily from user industries?

Submitting your early opinion on the above, and any other related subjects to Mr. Miller is most desirable.

It might be of interest to point out that the Houston Section of ISA appointed a committee on which Mr. Miller served, which made a survey earlier this year as to the potential interest in the immediate Houston Area. The Survey indicated that this Area alone should provide sufficient attendance to make a Maintenance Clinic worthwhile to all concerned and the much larger potential attendance in conjunction with the ISA Conference in Houston promises to make this one of its most attractive features.

Lyman Allen Appointed Chief Engineer at Snell

Lyman H. Allen, Jr., formerly Assistant Chief Design Engineer in charge of Chemical Process Design with the American Viscose Corporation in Philadelphia, Pa., has been appointed Chief Engineer of Foster D. Snell, Inc., New York firm of chemical and engineering consultants.

A graduate of Massachusetts Institute of Technology, Mr. Allen has authored several articles on automatic process control and the operation and control of fractionating columns.

He is a member of the American Institute of Chemical Engineers, American Society of Mechanical Engineers, and the Instrument Society of America. Mr. Allen is a highly active member of the Philadelphia Section ISA and at present Chairman of the National Society Publications Committee.

He will be in charge of the Snell Engineering Division supervising the design and construction of spray dryers, pilot plant operations, plant inspections, by-product utilization, and other engineering services offered by this organization.

Mr. Allen resides in Mountain Lake, New Jersey.

REGISTER *Continued from page* 1295

future operation of the Employment Register.

1. Insofar as possible determine the approximate salary or hourly rate for the open positions. The few positions posted which gave this information received a much better response then those which only gave applicant requirements.

2. A map of the U. S. and Canada be provided so that the location of open positions may be identified with pins or markers. Geography seemed to have important consideration in the minds of the applications.

3. A bulletin board be provided for posting "Interview Announcements" giving names of prospective employer, applicants to be interviewed, location and time of interview.

4. Separate applicants into the following mobile files to allow more employers to use the files at the same time and facilitate the finding of the right men for the job.

a. Mechanics	d. Chemical Engrs.
b. Mechanical Engrs.	e. Physicists
c. Electrical Engrs.	f. Sales Engrs.

It is strongly recommended that the Employment Register be physically located in the immediate vicinity of the exhibits as it is felt that the success and heavy activity in Buffalo resulted from being located where many people had to pass in order to see all of the exhibits.

—John D. Duthie, *Chairman*
Employment Committee,
Niagara Frontier Section

OFF THE RECORD

A convention is where a group of people, who believe that individually they can do nothing, gather and decide as a group, that nothing can be done.

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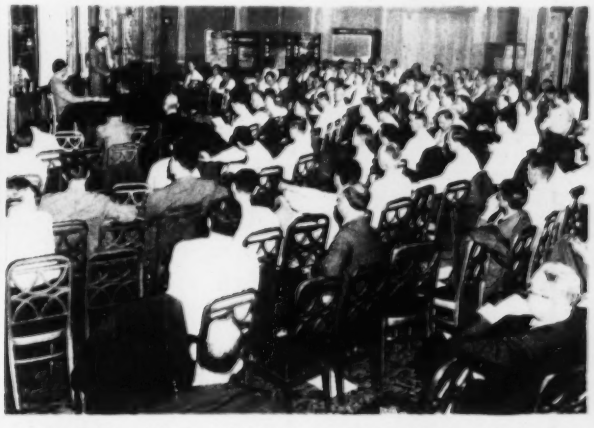
Scenes at the Philadelphia Section Regional Symposium on Industrial Waste Disposal



Above left, Speakers Table, standing left to right: Nelson Gildersleeve, National Vice President ISA; Francis S. Becker, Philadelphia Section Vice President; J. R. Hoffert, Chief Engineer, Pennsylvania Dep't of Health; W. J. Gallagher, Philadelphia Section President. Seated, left to right: Richard Rimbach, Executive Secretary, ISA; Dean Thorndike Saville, College of Engineering, New York University; R. J. S. Pigott, National President ISA; R. T. Sheen, Chairman, Symposium Committee; Louis Gess, Minneapolis Honeywell Regulator Co.; Bruce Dickerson, Hercules Powder Co.

Above right: Technical Session.

be able to supply sales department with answers to application problems. Location Michigan. Box 408.

CHEMISTS OR PHYSICISTS. M.S. degree or equivalent experience for positions in physical instrumentation. Knowledge of fundamental physics, electronics, and chemistry is requisite. Applicants should have interest in and aptitude for development of special instruments and their application. Give full educational and employment background and salary expectations. Location Missouri. Box 409.

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MATERIALS ENGINEER GS13. Structures Research Dept. At least one year of experience in performing tests and conducting research in field of engineering materials at the GS-12 level. Experience included work with concrete aggregates and supervising research projects relating to concrete.

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MECHANICAL ENGINEER. GS12. Evaluation Dept. Test and development experience. Plant and heavy machine experience.

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Some Design Considerations in Connection With the Use of High Speed Thermometry for Telemetering

By VERNON C. WESTCOTT *

In most radio telemetering applications one of the prime requirements is that the instrumentation be suitable for use with light-weight and functionally-simple telemetering equipment. It is usually not feasible to operate a mechanical repeating mechanism for the purpose of running potentiometers or other devices used as the input for the telemetering equipment. This is an almost basic difference between this class of equipment and the perhaps more familiar telemetering system used on power lines.

The most frequently used electrical devices for measuring temperatures are thermocouples and resistance thermometers. It is to be realized that the thermocouple is a differential device and must have a cold junction that is either compensated or is at a known temperature in order that absolute temperature measurements can be made. The resistance thermometer, on the other hand, is an absolute temperature measuring device in the sense that it requires no additional reference, the resistance being a single-valued function of temperature.

Because variations in vacuum tube characteristics, such as contact potential, emission, etc., result in an equivalent input voltage often much greater than the output of a thermocouple, it is usually not feasible to couple the thermocouple into a d.c. amplifier directly. a.c. amplification may be used if the output is chopped mechanically, but this solution results in size and weight limitations that are rather severe. Ideally, what is wanted is a temperature measuring device capable of delivering alternating current. The resistance thermometer is such a device.

The resistance thermometer is ordinarily used in a bridge circuit that is excited by an a.c. voltage from the telemetering system. The output voltage of the bridge is a certain fraction of the input voltage, depending on the temperature being measured. It is essentially a ratio device like a potentiometer. The change in voltage output over a given temperature range can be adjusted by varying input voltage, by selecting wires of varying temperature coefficients, or by varying the ratio of active to inactive resistance in the bridge. By active resistance, I refer to that part of resistance that is located in the temperature sensing element itself and which changes with temperature. The inactive resistance is usually located in the bridge and is required to remain constant. It is, therefore, possible by choosing varying amounts of active resistance to make instruments having almost any arbitrary range for a given number of millivolts output per volt applied to the bridge. For example, if it is desired to have a bridge capable of delivering 5 millivolts per volt applied, platinum resistance thermometers can be made capable of giving this range over a few degrees centigrade to more than a thousand degrees centigrade.

At the present time it is feasible to design these instruments for use at temperatures up to 1100° C. or approximately 2000° F. (corresponding to yellow-white heat). Some of the problems that have occured in connection with thermometry at these very high temperatures are covered below.

The a.c. output of the resistance thermometer bridge can be amplified by a.c. amplifiers with negative feedback so that the gain is maintained constant. It is also possible to obtain phase angle modulation by combining the output of the bridge with a quadrature voltage. This phase shift signal then contains the information to be amplified and telemetered. One of the advantages of this system is that the amplifier does not have to have constant gain since changes in gain will not change the phase angle. The use of the amplifier in this manner implies a trading of stability of phase shift for stability of gain in the amplifier. Fortunately, it is a very simple matter to build amplifiers having time delays that are a very small fraction of the period of the a.c. voltage being amplified. Changes in the time delay through the amplifier will therefore have a very small percentage affect on the phase of the carrier voltage. For example, subminiature amplifiers are now manufactured, having a phase shift change over the temperature range −40 to +71° C. of only 0.01 degrees at 1000 cycles per second. If the information

* President, Trans-Sonics, Inc., Bedford Airport, Bedford, Mass.

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Statements and opinions expressed in these articles are those of the author and not necessarily those of the Society.

were contained in a phase shift of 30 degrees, this would correspond to a shift of only one part in 3000 or one thirtieth of one per cent . This is therefore a very powerful technique for amplifying and conveying the information.

One of the greatest problems in connection with the developing of electrical thermometers is that of obtaining a sufficiently short thermal time constant. This is particularly true for most radio telemetering projects because the time of flight is usually short and it is often desired to measure temperatures that rise and fall in a few seconds. It can be understood that the time constant of the thermometer must be short compared with the duration of the phenomenon. This problem results in quite different methods of packaging for units designed to measure gas temperature, liquid temperature, or the temperature of solid structures.

For the measurement of air temperature it has been found that open resistance windings offer extremely short time constants and a high degree of reliability, providing hydrogen-free, noncorrosive gases are being measured. The unit illustrated has a thermal time constant of approximately 0.1 second in air of 5 ft. per second velocity. It is therefore possible to measure the temperature change occurring on an inhale-exhale cycle of a human being. The thermometer measures alternately room and body temperature giving essentially a square wave output on an oscillograph.

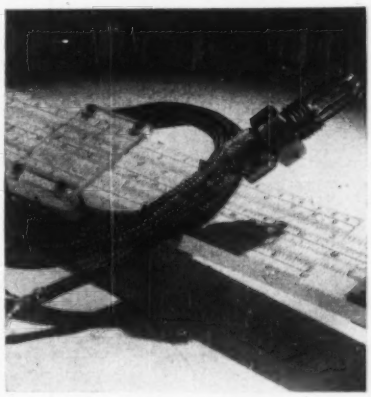
Ordinarily, liquid temperatures are measured by the use of a bulb type of thermometer. The bulb consists of a cylindrical tube, one end of which contains the sensing element and the other end a hexagonal nut and screw assembly suitable for installation in tanks and pipes under pressure.

The principal problems in the construction of such a pickup is in devising methods of supporting the resistance sensing element in such a way that the thermal path to the outside is of minimum thermal impedance combined with a low total thermal mass, so as to insure a short thermal time constant. Ideally, one would like to wind the resistance wire on the inside of the supporting tube. Although this is extremely difficult to do, it is possible to fabricate an almost exact equivalent by the use of a metal-ceramic-metal sandwich. The sensitive winding is held in a thin layer of ceramic between the two layers of metal. Adequate electrical insulation can be provided by a layer of only .003 in. thick, and the sensitive wire is contained within this layer as a spiral winding. The total thickness of the metal-ceramic-metal sandwich can be held to less than .010 in. With these techniques, instruments have been built that have thermal time constants of less than two seconds in water.

The electrical leads are welded and are insulated with ceramic beads, and all Class A insulating materials are eliminated from the structure so that high lead temperatures are not harmful. Small size bulbs capable of operating at 1100° C. (2000° F.) have been manufactured.

Sensing elements of the metal ceramic metal construction have also been designed for the measurement of structural temperatures. The element has the form of a flat plate which may be mounted on the structure to be measured. The time constant in this case is dependent on the thermal impedance between the plate proper and the structure. It is customary to reduce the thermal impedance by putting a thin smear of silicone grease underneath the plate. The silicone grease of course cannot be used at temperatures above 300° C.

At the present time a great deal of



effort is being expended in the development of high temperature units suitable for use at 1100° C. (2000° F.). The problem is one of providing an external case capable of withstanding the high temperatures, of providing high temperature insulation and of suppressing conduction in the insulation. In most applications, the strength of the case material at high temperature is important and many otherwise suitable materials are ruled out. Nickel and inconel have proven satisfactory for most applications. Although inconel discolors rapidly it is extremely resistant to oxidation and offers good structural strength even at 1000° C.

Titanium dioxide, magnesium oxide and aluminum oxide have been used as insulating materials. Aluminum oxide is being used for most of the high temperature applications at the present time because thin layers of the material can be tightly bonded to metal to provide the metal-ceramic-metal sandwich discussed previously.

Ionic conduction in the insulating material has been a severe problem and special effort must be made to eliminate all sources of ions or other contaminants that will lower the specific resistivity of the insulation. It is of interest to point out that the cathode in an ordinary radio receiving tube operates at 850° C. and that these insulating coatings in question have to operate at temperatures nearly 300° C. hotter. As ceramics are heated it is found that their specific resistances decrease in a manner similar to that of semi-conductors. Ionic conduction appears to occur and polarization effects are clearly noted. The approach to the problem has been to increase the resistance of the ceramic coating to such a point that these effects are no longer troublesome. The ceramic must be scrupulously clean and all components that will ionize (such as cements containing sodium silicate) must be eliminated. It should be noted that at these high temperatures the resistance changes of platinum are very large and therefore the influence of shunt resistance on the percentage accuracy is not as serious as it would be in units designed for lower temperature. Experience has shown that it is necessary to operate each high temperature unit at its maximum temperature rating before calibration and shipment from the factory, because the resistance of the insulator drops to a low value during initial heating.

One of the principal requirements of telemetering instruments is that they be suitable for installation aboard aircraft without the necessity of recalibration or other checks. In addition, it is most desirable to have interchangeable instruments for the measurement of all quantities. This is particularly useful when the instruments are to be commutated because it is then necessary to have the same output for all pickups in the commutator equipment.

One advantage of the resistance thermometer bridge is that it can be arranged to simulate exactly the output of strain gage and other resistance bridge pickups. It is therefore possible for the user to measure pressure, acceleration, temperature and strain with identical telemetering inputs.

Below are comments on some of the equipment that has been used in connection with these thermometers. For operation at fixed location and for those applications where the utmost reliability is required such as in engine controls for aircraft, the magnetic amplifier offers many advantages over the more familiar electronic devices. In general, the time constant of the magnetic amplifier can be made equal to or shorter than those of the thermometers. The magnetic amplifier is essentially a power amplifying device and may be designed for a wide range of input and output impedances, depending on the requirements.

At the present time, units having input impedances varying between 2 ohms and 20,000 ohms are being manufactured. A single stage push-pull magnetic amplifier can be arranged to have a power gain of about 50,000 per stage. It is often, however, very desirable to introduce negative feedback for the purpose of stabilizing zero and sensitivity. One typical unit has a zero shift that is equivalent to less than 1×10^{-11} watts at the input terminals over a period of several weeks. The power gain in this case is 15,000 per stage.

The resistance thermometer and its associated bridge can be designed to simulate other resistance bridge instruments such as the strain gage pickups. They can be made exactly interchangeable, both as to input and output resistance and voltage output over the specified temperature range. Ranges varying between a few degrees centigrade and more than 1000° C. can be manufactured.

Rupture-proof Bellows-type Flow Meters

By CLAUDE B. NOLTE *

The use of flexible metallic bellows or diaphragms as a means of measuring differential pressures, while not as ancient as the various forms of the manometer, is by no means a newcomer to the field of instrumentation. Metallic bellows were used in the manufacture of aneroid barometers nearly 100 years ago. They have been used in differential pressure sensing devices for the purpose of measuring flow rates for at least 60 years. If operating pressures were of essentially the same magnitude as the differential pressures being measured, the single bellows-type meter could compete reasonably well with manometric types because there would be virtually no danger of damage due to over-ranging of the bellows mechanism. However, even in the field of water flow measurement, where differential pressure devices were first used, operating pressures are high enough to drastically reduce the usefulness of single bellows-type meters. As the chemical and refining industries began to grow to their present stature after the close of the first world war, the operating pressures of flow meters rose ever higher and higher. With this growth, the likelihood of damage to single bellows-type meters grew by leaps and bounds. Even skilled personnel would find it difficult to place high pressure meters in service without occasionally rupturing the bellows.

In contrast to a single bellows-type meter, the mercury-type meter will be only temporarily rendered inoperative if the mercury should be blown when the meter is over-ranged. Correcting the difficulty is usually possible in the field. With the older single bellows-type instrument, however, if the sensing mechanism is damaged as the result of over-range it is generally necessary to remove the unit from service and make the repair in an instrument shop. Similarly, the repair requires a higher degree of skill than is the case in refilling a mercury meter. Therefore, this imminent danger of damage to single bellows-type meters presented a serious obstacle to their general acceptance.

There was a second, serious objection to the use of single bellows-type instruments. Their inherent lack of inertia and moderately high natural periods of vibration rendered them virtually useless for the measurement of pulsative flows. This was especially true when the flow rate was to be recorded rather than just indicated. The recording pen would faithfully trace on the chart every variation in flow, but it was impossible to use the information so obtained. In other words, the result was a chart with a broad, soggy blur. The pulsative flows associated with reciprocating pumps and compressors are not the only ones that gave trouble. The high frequency pulsative flows generated by centrifical pumps will cause vibration in diaphragm and single bellows-type flow measuring apparatus. The audible noise produced by pressure reducing valves consists of a number of different frequencies, which by overlapping create beat frequencies in the gas stream which have periods low enough to deflect the average single bellows or diaphragm type meter.

In spite of these two difficulties, the basic advantages of a bellows-type meter over the manometric type have

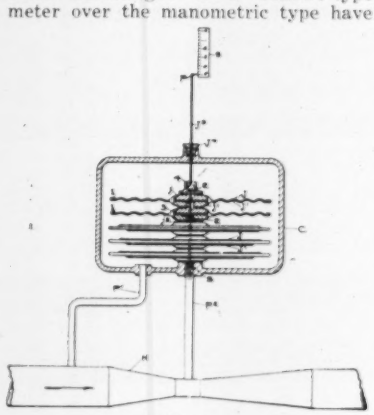


Fig. 1

led various and sundry manufacturers to search for means of eliminating the disadvantages of the single bellows-type meter.

One of the early attempts to solve the difficulty of over-ranging involved efforts to design the bellows in such a way that it would fold upon itself as an excessive differential pressure was applied. (See Fig. 1) Such an approach had two fundamental weaknesses. In the first place, even though the bellows did fold upon itself, some distortion would take place which would appear as a shift in zero position. Even assuming that the bellows could withstand a high normal differential pressure across it with such a design, it would become wholly useless should the differential pressure accidentally be applied in the reverse direction. Such a situation is, of course, by no means uncommon in actual operating practice.

Another attempt to eliminate the damage to bellows revolved around the introduction of some sort of relief device, which would permit the excessive differential pressure to by-pass around the bellows and thereby reduce the likelihood of distortion. One of the early devices employed a rupture plate which would be perforated by a knife when the bellows travel approached the safe limit. (See Fig. 2) For moderately excessive differential pressures that were not applied too rapidly, this system worked reasonably well. It had the disadvantage, of course, of requiring the replacement of the punctured disc before the instrument could be returned to service. Spring loaded relief valves, currently being used to protect single-bellows type meters, offer obvious advantages from this standpoint. Undoubtedly they do give a degree of protection to the bellows mechanism provided they do not become inoperative as the result of dirt or corrosion interfering with the action of the relief mechanism or holding the by-pass valve open, thereby permitting the passage of some measured fluid through the instrument. When a high level overload is supplied very abruptly, it is doubtful, however, whether these relief valves can wholly prevent bellows damage.

The last and most practical method of eliminating the inherent disadvantages of the single bellows-type differential pressure meter has been the development of a bellows system that is within itself, truly and completely rupture-proof. (See Fig. 3) This design consists, in essence, of two bellows mounted on opposite sides of a center plate. One bellows is exposed to the higher pressure, the other bellows exposed to the lower pressure. The two bellows are mechanically linked by a stem which passes through the center plate and is attached to the closed end of each bellows. On this central stem are mounted two valves which seat against the center plate when the normal bellows travel in either direction has been exceeded. This assembly forms, in essence, twin chambers joined by the annular passage around the center stem. The twin chambers, as well as the annular passage, are completely filled with a low freezing point liquid and sealed. No trace of air is permitted to remain within either of the two chambers.

When a differential pressure is applied to the instrument, both bellows move simultaneously because they are mechanically linked. The bellows chamber on the high pressure side decreases in volume slightly while the bellows chamber on the low pressure side increases a corresponding amount. For this to take place, fill-liquid must be transferred through the annular passage from the high pressure bellows chamber to the low pressure bellows chamber. This transfer of liquid continues until the allowable travel of the bellows has been reached. At that time, one of the valves mounted on the center stem seats on the center flange. The further transfer of fill-liquid from one side of the bellows system to the other is thereby completely prevented. In essence then, the fill-liquid in the chamber subjected to the higher pressure is trapped. Thereafter, the pressure level in the one housing may be raised to the safe working pressure of the instrument with no corresponding increase in the pressure in the opposite housing and the bellows will not be damaged. You see, a bellows will sustain damage only if its shape is distorted. When the liquid is trapped within, there is no possibility of such distortion.

The valve used to seal off the transfer of fill-liquid from one side to the other is a neoprene "O" ring. It closes

* Vice President, Barton Instrument Corp., Los Angeles, Calif.

NOTE: Presented before the Fifth Annual Convention of the Instrument Society of America, at Buffalo, N. Y., Sept. 12-18, 1950.

into a conical seat, thereby creating a tighter seal the higher the differential pressure becomes. There is no time limitation on how long the over-load may be applied; once the valve closes, the soft "O" ring forms an absolutely leak-proof seal.

The protection against damage by over-ranging is effective regardless of the direction of application of the excessive differential pressure. That is to say, the low pressure chamber may be subjected to a high pressure level with the high pressure chamber open to atmosphere or vice versa, and no damage will be sustained by the bellows. This comes about because as previously mentioned, two valves are mounted on the center stem, one within the high pressure bellows chamber and the other within the low pressure bellows chamber.

Because the fill-liquid is hermetically sealed within the twin chambers, provision must be made for changes in the volume of the fill-liquid resulting from variations in ambient temperature. Extra free-floating convolutions have been provided on the high pressure bellows assembly which act as a surge chamber. There is a communicating passage between the temperature compensator, as this chamber is called, and the high pressure bellows chamber itself. Therefore, as the fill-liquid expands, the excess liquid flows into the temperature compensator and bulges it out slightly. As the fill-liquid contracts, some makeup liquid will flow from the temperature compensator into the high pressure bellows chamber. Without the use of the temperature compensator, the pressure within the bellows would rise above the system level to some extent, thereby changing the shape of the individual bellows convolutions. With lower differential pressure ranges especially, this would be unsatisfactory because it would result in a noticeable change of calibration. Similarly, no two bellows, however carefully made, have exactly the same effective area. Therefore, with a sensible increase in internal pressure, the bellows assembly would drift slightly in the direction of the larger bellows. The result would be of course, a zero shift. Therefore, the temperature compensator is a vital, necessary part of the rupture-proof bellows mechanism.

The differential pressure range of the meter may be altered by the customer in the field by simply replacing the range spring assembly. In a typical meter, for example, if the range spring assembly is eliminated entirely, the differential becomes 20 in. W.C. By introducing successively stiffer springs, the differential pressure range may be increased to as much as 300 in. W.C. without a change in size of the meter itself. The actual strength of a given spring may vary as much as 5 per cent. Therefore, final calibration is made by adjusting a lever length within the instrument case, just as would be done for pressure or temperature measuring system.

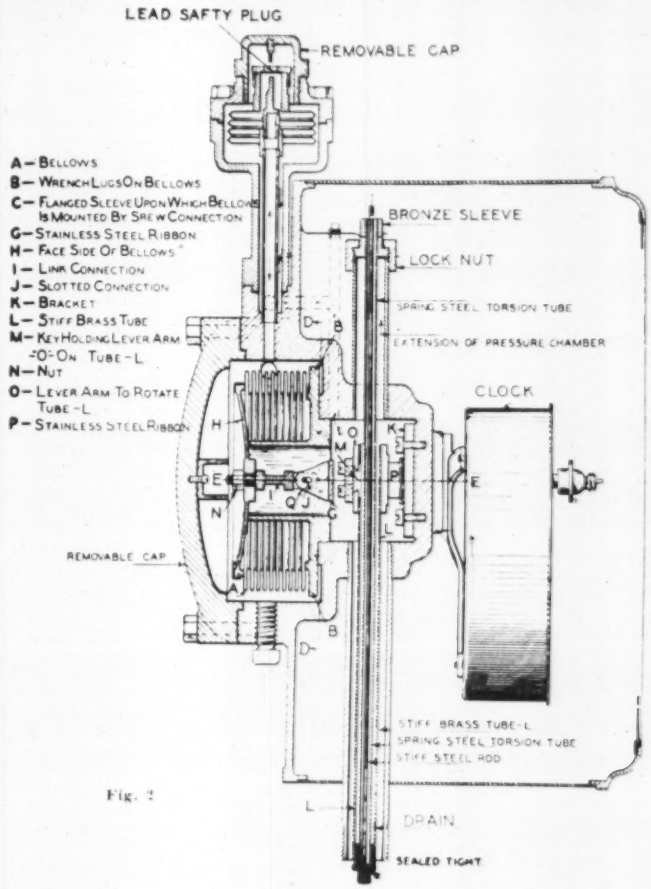


Fig. 2

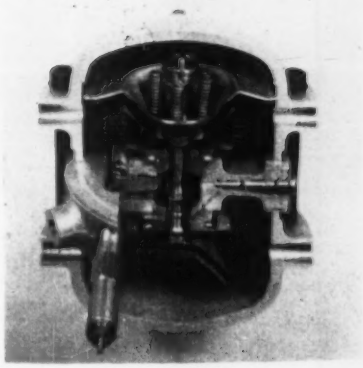


Fig. 3

Special bellows were required in order to take full advantage of the rupture-proof bellows system. (See Fig. 4) They have been made relatively short with rippled, deep convolutions and with large effective areas. Because commercially available bellows did not meet these specifications, a unique process of assembly was developed to produce bellows of the desired shape and size. Individual diaphragms are formed from stainless steel sheet. These diaphragms are assembled by slipping the turned-down flange of one diaphragm over the flange of the next. The flanges are joined at the inner and outer point of contact by a process of seam welding. This special welding process, developed after two years of research, joins the two diaphragms together so quickly there is practically no carbon precipitation which usually occurs when stainless steels are welded by arc methods. Such precipitation would reduce corrosion resistance by permitting inter-granular attack. (The same process of seam welding is used to join the bellows to the valve seats and to seal the ends of the bellows). Because the metal is not stretched drastically, during the shaping of the bellows, as is the case with most hydraulically formed units, the possibility of stress corrosion along the outer edges of the bellows is virtually eliminated.

The movement of the bellows is in direct proportion to the differential pressure applied. Before this movement may be used to drive an indicator, recorder, or controller, it is necessary to transmit it outside the pressure housings. This is done by converting the linear motion of the center valve stem into a rotary motion of shaft. (See Fig. 3) The drive disc, located on the center stem, transfers the lateral

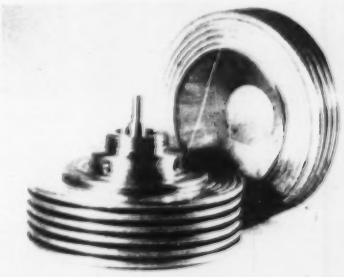


Fig. 4

motion to a follower arm connected to the inner end of a torque-tube assembly. The torque-tube permits the transfer of the bellows motion to the outside of the pressure housings without possibility of leakage and without the need for periodic lubrication.

While the use of a torque-tube is not new in the instrument industry, it may be worthwhile to take a moment to review, briefly, its method of operation. A torque-tube is a mechanism which permits a rotary motion to be transferred from the inside to the outside of a pressure vessel without a physical communicating passageway as is required with a stuffing box or pressure-tight bearing.

The entire torque-tube assembly is sealed within the bellows mechanism and therefore comes in contact only with the fill-liquid. Such a construction offers distinct advantages, because ball and needle bearings may be used at those points in the system where friction might otherwise develop. These two places are, the point of contact between the follower arm and the drive disc, and the inner end of the torque-tube. The use of ball and needle bearings at these points makes it possible in produce an instrument that has a sensitivity of 1 part in 5000. Such degrees of sensitivity are of no particular value in the indicating or recording of flow rates, but they do have certain advantages when the equipment is being used to control flow rates.

The line fluid being measured comes in contact only with the exterior of each bellows and since pressure connections are provided at the bottom of the housings as well as at the top, the instrument automatically becomes self-draining. This means that if condensate should form in the instrument housings, it will drain automatically and completely to the lowest point in the system.

There are advantages to this design feature, because the expense of installation and maintenance of seal pots is eliminated without sacrifice of instrument accuracy. However, to obtain full advantage of this self-draining characteristic, the manifold and meter piping must be designed to eliminate the formation of traps, either in low places in the meter piping or in valves having small, angular passageways. Liquid caught in either of these two locations can result in minor instrument inaccuracies.

An additional example of the advantage of a completely self-draining meter can be seen in those areas where high pressure gas containing water vapor is to be measured. There is always the possibility of the formation of gas hydrates if the atmospheric temperature drops below the critical level. Gas hydrates are snow-like substances that are formed by a loose chemical union between water and natural gas. The temperature of formation increases as the system pressure becomes greater. At pressures of 500 psi., it is approximately 60°, at pressures 1000 psi., approximately 70° and at pressures of 2000 psi., approximately 80°.

The formation of gas hydrate can interfere with flow metering operations in various ways. If a mercury meter is used, it can form layers of gas hydrate on the two surfaces of the mercury. This, of course, effectively locks the meter. With a rupture-proof bellows-type meter, the absence of pockets for the accumulation of water practically eliminates the possibility of locking of the meter as the result of the hydrate formation within the pressure housings, provided the meter is permitted to drain. Gas hydrates, however, may form in the innerconnecting meter piping at elbows or in the small passages of needle valves. Gas hydrate is most easily formed where the gas can bubble through water. A few drops of water, therefore, collected in the small passages of a needle valve pro-

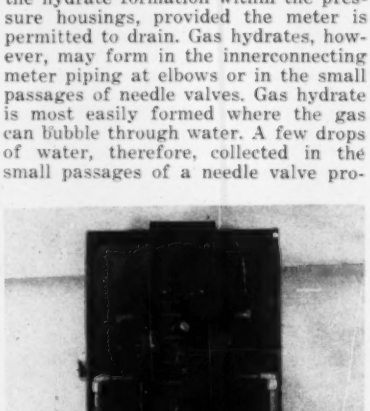


Fig. 5

vide an ideal spot for their formation, with the resultant loss of instrument operation. Therefore, it is essential, if the advantages of the rupture-proof bellows-type meter are to be obtained where hydrate can form, to use meter piping of adequate size and some type of full opening block valve such as a plug cock.

As was previously mentioned, an effective method of controlling the rate of instrument response is absolutely essential for a practical, bellows-type differential pressure recording meter. Since, in the rupture-proof, dual-bellows design, fill-liquid is transferred from one bellows chamber to the other as a differential pressure is applied, the rate of instrument responsiveness may be regulated quite readily if the rate of transfer of fill-liquid is controlled. To accomplish this objective, the rate of flow of fill-liquid can be drastically reduced by the introduction of a free floating, but closely fitted, piston ring installed on that portion of the center stem which passes through the high pressure valve seat. The tolerances can be selected so that the rate of responsiveness is slower than would be required for commercial application. Control over the rate of responsiveness can be obtained by diverting some of the fill-liquid around the restriction through a by-pass needle valve. Thus, the rate of flow of by-passed liquid may be selected while the instrument is in operation and under pressure. Thereby, the response rate of the instrument may be adjusted to the particular degree of pulsation being encountered in any application. Because there is always a slight leakage of liquid past the restriction ring, it is impossible to completely lock the meter if the by-pass valve is entirely closed. Under such circumstances, the rate of response of the instrument is very slow indeed, but continuous. Therefore, when pulsative flows of such a nature as to require extreme dampening are being measured, there is no possibility of the operator accidentally locking the meter and thereby loosing all record of the flow rate.

The entire apparatus for controlling pulsative flows is incorporated within the sealed bellows system. Therefore, there is no possibility of the dampening mechanism being rendered inoperative by scale, corrosion or dirt. Because the flow from one chamber to the other is the sole means of controlling the responsiveness of the instrument, there is no chance of introducing errors which result when two external lines pulsation dampeners are used and not adjusted to provide exactly the same degree of snubbing.

The experienced user of any equipment always wants to know its actual operating limitations. His desire for this knowledge works to his benefit and to the benefit of the manufacturer as well. One of the first questions that is always asked in regard to rupture-proof bellows-type flow meter is, "Can they actually be over-ranged safely?" The answer to that question is, "Yes, they can". Each instrument is tested at the factory by applying a differential across the bellows assembly equal to the static pressure rating of the instrument. This is applied in the normal direction of differential and in the opposite direction as well. Several years ago, during the earlier stages of development of this instrument, one customer tested the efficiency of the over-range mechanism by applying a differential pressure of 300 psi. across an instrument with a 25 in. range. This was an over-load of at least 300 times the instrument range. These tests were conducted at a pressure level of approximately 1200 psi. The differential pressure was alternately applied in the normal direction of differential and then in the reverse direction. The pressures were reversed approximately 20 times per minute and the tests were continued day and night for three weeks. The net result was the application of one-half million over-range in both directions. At the conclusion of the tests, the instruments was checked for zero position and calibration and found to have changed less than 1 per cent.

Potential customers sometimes ask, "What will happen with the passage of time? Will the "0" rings wear out, or will the unit fail in some other way?" The test involving a half million over-range cycles rules out the breakdown of the over-range valves. Certainly it is highly unlikely than an instrument would be subjected to even a small percentage of that many occasions for these valves to close in a normal lifetime. Of course, if the bellows should be perforated by an accidental blow, or by the action of ex-

remely corrosive fluids, the fill-liquid ould either become contaminated or ak out entirely. If the instrument ere operating in a liquid service, this itself might not be overly serious. If he instrument were in high pressure as service, however, the gas would ssolve in the fill-liquid and, assuming hat the fill-liquid did not escape from he bellows, no damage would be done ntil such a time as the instrument as depressurized for one reason or nother. Then, the gas, boiling rapidly ut of the fill-liquid, would balloon the ellows and probably rupture it.

In summary then, let us review the dvantages to be found in rupture-proof ellows-type flow meters. (See Fig. 5) hey are about as easily installed as pressure gauge because they require o precise levelling, there is no mer-ury to pour into the meter, and gen-rally speaking, seal pots are not required. In most instances, the meter piping is simplified because it may be dropped from the instrument right into the orifice flanges. Mercury traps in the meter piping are eliminated. All these things contribute to a markedly lower installation cost.

The accidental over-ranging of the rupture-proof bellows-type meter will not damage the sensing element or render the instrument even temporarily inoperative. This means the equipment can be safely handled by less skilled operators.

The torque-tube, which is ideally suited for use in bellows-type meters, contributes to markedly lower operating costs because the problem of maintaining or replacing pressure bearings is eliminated. Furthermore, the frictionless characteristics of a torque-tube are permanent, thereby assuring continuous measurement accuracy.

By virtue of the basic design, the rupture-proof bellows-type meter can be internally dampened, thereby offering the operator complete control of the response to pulsative flows. Furthermore, the response will not be affected by the corrosive or plugging tendencies of the fluid being measured.

The absence of mercury in a rupture-proof bellows-type meter makes it particularly useful under some circumstances. For instance, mercury may form explosive compounds with substances like ammonia, it will react with oxygen, it will emulsify with sulphur bearing oils and gases, and it will contaminate materials used in the photographic or food industries. In such circumstances a rupture-proof bellows-type meter is essential in many cases, and at least desirable in others.

Pneumatic Weighing in Process Control Systems

By J. E. VOYTILLA *

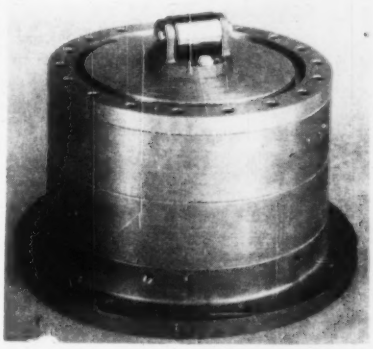
The pneumatic weight transmitter or r scale is a new development in the eld of instrumentation. The principle f operation of the air scale is not ew but use of the device for the solu-on of industrial weighing problems a recent development. One of the rst applications of this device was he measurement of torque or thrust f aircraft engines under test. A num-er of air scales were used in this way uring the last war, and since that me they have found increasing use s individual weighing units, and as arts of complex process control sys-ms.

Manufacturers and users of the air ale are gaining valuable experience om recent industrial installations and e results to date appear quite prom-ing even under the adverse operat-g conditions often encountered in emical plants. Our purpose at this me is to stimulate interest in the sub-ct by bringing to light a few of ese practical applications, and indi-ating inherent advantages of such stems.

Fig. 1 shows a modern pneumatic eight transmitter which is designed the force balance principle. In op-ation, weight on the platform adjusts e bleed nozzle opening until the re-lting air pressure times the effective ea of the diaphragm equals the eight on the platform. This air pres-re bears an exact and linear relation-ip to the weight supported. There-re, a pressure measuring receiving strument indicates weight directly. he tare-weight chamber is air-loaded a pressure regulator to counter-alance any fixed load on the platform that the output pressure from the t weight chamber is a direct meas-rement of net weight only. The damp-er chambers are required, because frictionless design, to produce uni-rm measurements of weights subject to vibration. This unit contains single net and tare weight chambers, but multiple chambers are available to permit increased load capacity with a given air pressure, or independent loading of the air chambers in certain complex control systems.

Pneumatic weight transmitters are being manufactured by several instrument companies. One manufacturer can supply twenty-three different models with effective diaphragm areas from 4 to 465 sq. in. to support loads from 60 to 7000 pounds with 15 psi. output pressure, or 200 to 23,000 pounds with 50 psi. output pressure. Output pressures to 100 psi. may be used in the smaller sizes. In most applications involving the heavier loads only one-half the total load is supported on the scale platform, the other half being supported by sealed anti-friction bearings.

The weight transmitter places a new physical measuring element in the hands of the instrument and process engineer. Now one can indicate, record, and control weight or force through standard air control circuits using instruments in the same manner as applied to temperature, pressure, flow, and level. The transmitter, being air-operated, may be used directly with standard air-operated recording or controlling receivers, pneumatic integrators, pressure switches, etc., without the need of any secondary conversion unit. All of the moving parts are totally enclosed and are completely protected from the weather, corrosive atmospheres, dirt, and dust. Compared with conventional mechanical scales, the air scale unit is relatively free of knife-edge bearings, linkages, and mechanical moving parts subject to wear and corrosion. The air scale has very little friction and is capable of retaining its initial high sensitivity over a long period of operation. It is affected relatively little by loads subjected to vibration. Being air-operated, it introduces no explosion hazard, an important consideration in chemical plant instrumentation.



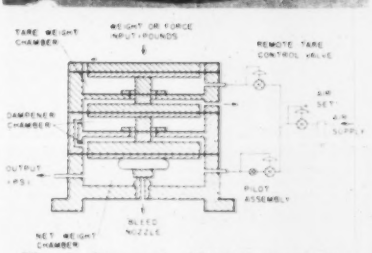


Fig. 1. Pneumatic Weight Transmitter

Air scales are finding increased use as individual weighing units, and are important parts of process control systems. Several examples of their use are described briefly below. Fig. 2 shows a pivoted belt feeder, having constant belt speed, in which the weight of flowing solids on the belt is utilized to make adjustments in feeding so that a fairly constant weight flow is obtained. In this example, the weight transmitter has tare weight and net weight chambers, and a standard transmitted or output air pressure of 3-15 psi. for 0 to full scale net load on the belt. The tare weight of the empty belt is supported by a regulated fixed air pressure in the tare weight chamber. Therefore, when the belt is empty, the air scale output pressure is 3 psi. and the recorded net weight is zero. Any load on the

* E. I. du Pont de Nemours & Company, Wilmington, Del.

NOTE: Presented before the Fifth Annual Convention of the Instrument Society of America, Buffalo, N. Y., Sept. 12-18, 1950.

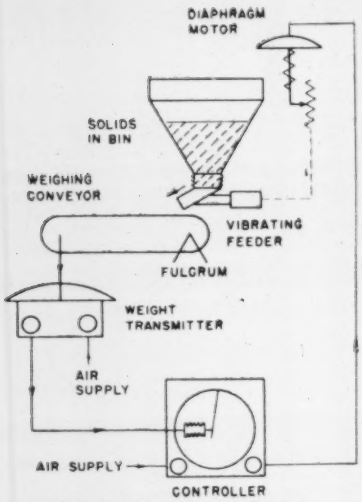


Fig. 2. Pivoted Belt Feeder

belt produces a proportional increase in output pressure to the standard recorder controller which adjusts the vibration amplitude of the vibrating feeder as required to maintain the feed rate for which the controller is set. The weight of solid fed could be totalized by operation of a standard pneumatic integrator from the transmitter air pressure.

Figs. 3 and 4 show a fuel weight system for engine laboratory testing which times the period for a given weight of fuel to flow from the tank. On operation of the start button the system will automatically stop the flow of fuel to the filled weight tank, time a fixed quantity of fuel discharged from the tank, refill and maintain a full tank ready for the next reading. In this installation the fuel tank is suspended from the weighing platform of the weight transmitter. The dead load of the tank is supported by the fixed tare weight chamber pressure, and the fuel weight is supported by the net weight chamber pressure as described in the previous example. In operation, fuel flows continuously through the tank to an engine, with the quantity of fuel in the tank being controlled by a pressure regulator setting on the operator's panel. The operator sets four air pressure regulators to control, first, the tare weight chamber pressure in the air scale; second, the maximum fuel weight in the tank by operation of a solenoid valve in the fuel line; third, the point of starting the timer which times the period for discharging a fixed weight of fuel; and fourth, the completion of the timed period. The last three air pressure settings by the operator constitute remote manual control of special pressure switches, described later, in which this air pressure is opposed by the air scale output pressure.

Fig. 5 shows a system for throttling control of weight of solids in a hopper which is discharging continuously through a volumetric feeder. Here the weight transmitter supports one-half of the weight of hopper and contents, the other half being supported by sealed antifriction bearings. Again, the hopper weight is supported by the tare weight chamber pressure, and the air pressure transmitted to the controller is a linear function of solids weight in the hopper. Because of the non-uniform distribution of solids weight in a hopper, special precautions must be taken in the design of the hopper supports to be sure that the air scale always supports a constant percentage of the total load. This may be accomplished by suspending the hopper from two diametrically opposite points which rest on horizontal members at points mid-way between the air scale and the sealed bearing supports. The development of the weight transmitter has not required the development of many special instruments to permit its application in complete instrument systems. The transmitter will operate with all standard pressure operated instruments. Two very important and frequently used devices have been developed, however.

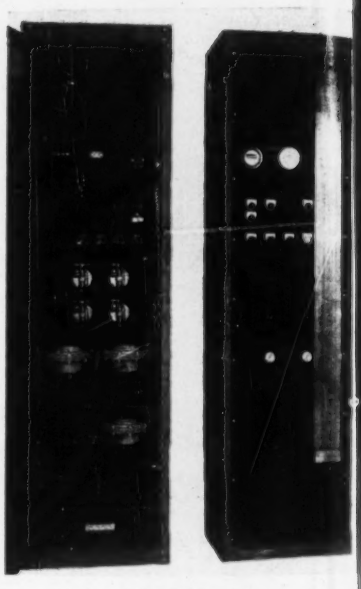


Fig. 4. Control Panel for Fuel Weight System

One is a motor-driven tare weight chamber pressure regulator (Fig. 6) in which a reversible electric motor equipped with limit stops adjusts the setpoints of a high grade air pressure regulator. This device is used in weighing systems to be described later where it is desired to adjust the tare weight chamber pressure automatically. The other device is a pressure switch which consists of a single pole double-throw Micro switch operated by the pressure difference across a flexible diaphragm. One side of the diaphragm is loaded by the output pressure of the weight transmitter, while the other side is loaded by the fixed pressure from a pressure regulator. This permits remote setting of the switch operating pressure at any time. The switch is mounted with the diaphragm horizontal and by control of the weight of the diaphragm plates any operating differential between two regulators is also obtained. Switches are available for positive operation with differential pressures as low as 0.05 in. of water.

Fig. 7 illustrates a fully automatic continuous weigh-proportioning feeder for a granular solid and a liquid. In this example the solid, or primary flow, is fed at a roughly constant rate by a volumetric feeder. Therefore, the feed rates will vary some, but the proportions on a weight basis are maintained constant. Although only one set of weigh tanks and controls are shown here for clarity, two similar sets with interlocks for changeover are required for continuous operation. The system described here can be readily expanded to weigh-proportion any number of solids or liquids. The complete operating cycle for each set of weigh tanks includes taring of empty weigh tanks, filling tanks to approximately the pre-set net weight, taring of full tanks, proportional weigh-feeding to a process until the tanks are emptied to approximately the pre-set net weight, and changing feed from empty to full tanks.

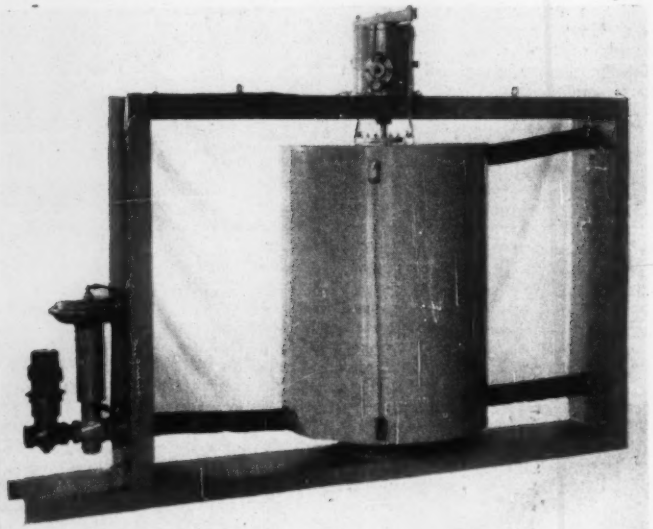


Fig. 3. Pneumatic Fuel Weight System for Engine Testing

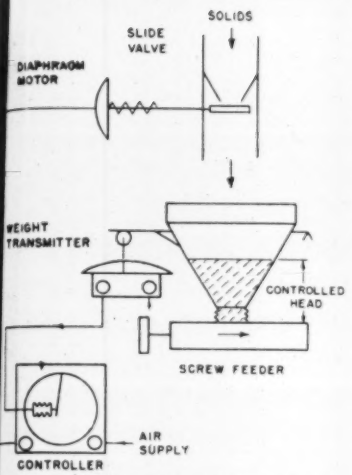


Fig. 5. Control of Solids Weight in A Hopper

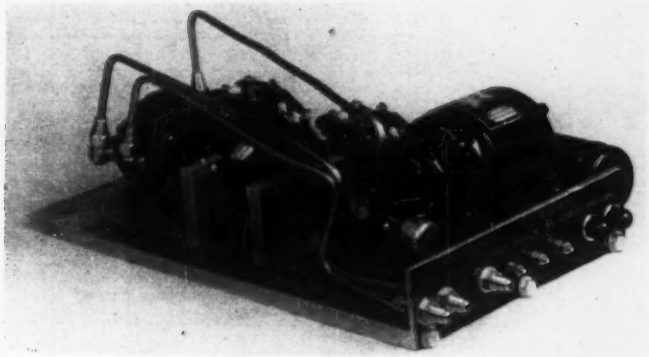


Fig. 6. Motorized Tare Weight Chamber Pressure Regulator

The essential requirements for accurate weigh-proportioning of two or more materials from a set of weigh tanks by means of the air scale are that, (1) the air output pressures of the pneumatic weight transmitters must bear a linear relationship to net weight in the weigh tank. This requirement is met to a satisfactory degree by air scales on the market, and, (2) the air output pressures from each weight transmitter in the weigh-proportioning system must be maintained equal from start to finish of the feeding part of the cycle. Any difference in output pressure is measured by the differential pressure relay which brings them into balance by adjusting the discharge valve on the secondary liquid tank. In this control system a change in ratio of the feed component is obtained by means of an adjustable base for the liquid tank air scale. This adjustment permits the scale to weigh more or less than the usual 50 per cent of the total load, thus changing the pounds of liquid fed per psi. change in air scale output pressure. An adjustable ratio air relay could be substituted for the adjustable scale base to obtain a change in feed rates.

The remaining devices in the control system consist largely of special sensitive pressure switches described previously to initiate the weigh tank filling and feeding steps, taring of empty and full tanks, and changeover from empty to full tanks to make the feeding operation continuous. An interesting point in this control scheme is the necessity for taring each weigh tank when empty and again after it is filled.

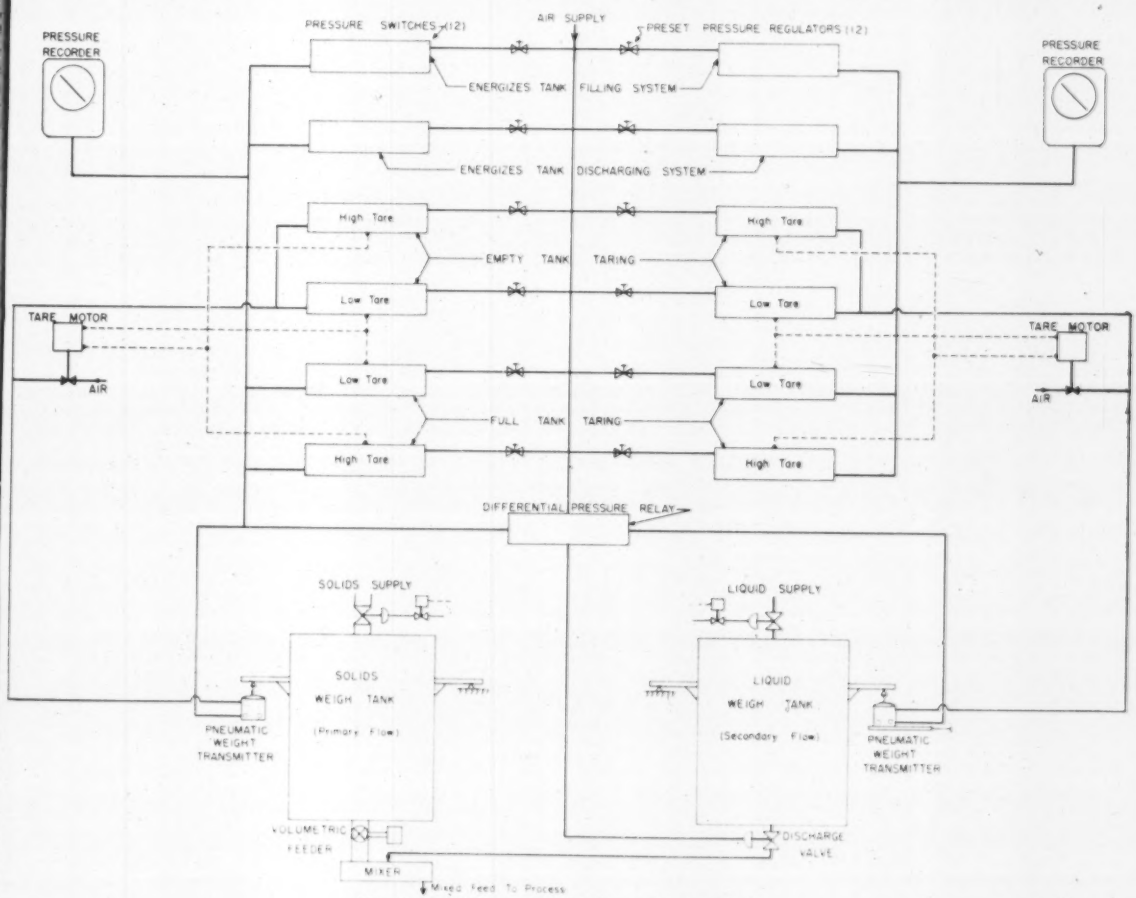


Fig. 7. Continuous Weight-Proportioning Feeder

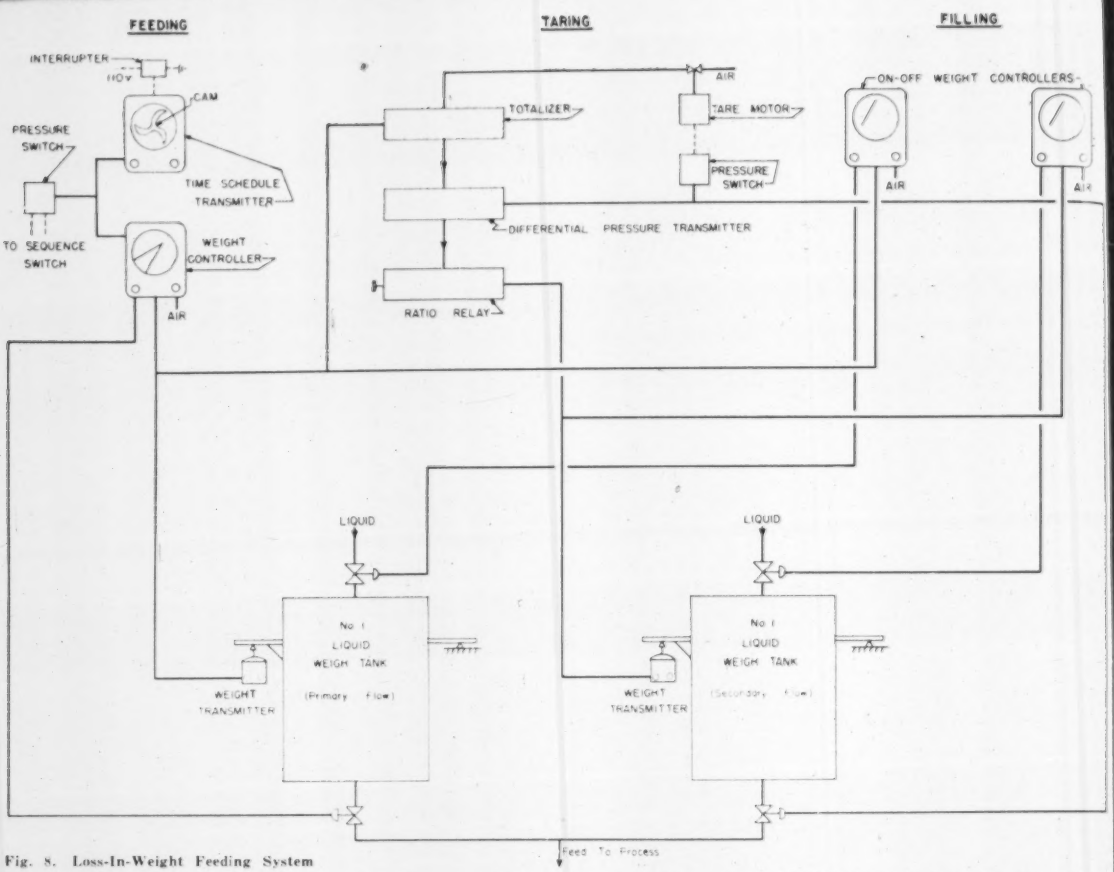


Fig. 8. Loss-In-Weight Feeding System

Taring of the full tanks consist of automatic adjustment of the tare weight chamber pressure of the air scale, to equal a standard net weight reference pressure, by use of the reversing motor-driven pressure regulator described previously. This permits the weigh-proportioning part of the cycle to start feeding with the system in pneumatic balance. Taring again when the weigh tank is empty consists in returning the tare weight chamber pressure to a standard value. This is necessary to make the recorded weight accurate, prevent accumulative errors in filling tanks, and to insure delivery of the same net pounds weight from a weigh tank every time.

This system provides good operating flexibility. Standard receiving instruments may be used for indicating, recording or controlling weight as transmitted by the air scale. The total weight fed from each tank is obtained with accuracy from the product of number of tank-fulls fed and the net weight delivered from the tank.

Fig. 8 shows a fully automatic loss-in-weight feeding system which is designed to deliver two liquids at a fixed pre-set rate and ratio, both of which are adjustable from a remote control panel. Although only one set of weigh tanks is shown for clarity, two sets of tanks with air scales are provided for use with one control system in order that one can be filling while the other is taring and feeding. The complete operating cycle includes weigh tank filling, taring, and feeding for both pairs of tanks. A four-position sequence switch which is not shown isolates the unused pneumatic and electric circuits at each step in the operating cycle.

Filling of weigh tanks to a pre-set weight is controlled by the on-off weight controllers, and the liquid charging valves. These controllers measure weight transmitted by the tank weight transmitters.

Taring of the filled set of weigh tanks begins the instant the other set becomes empty. This step must be completed before feed to the process can be resumed but requires only several seconds. The purpose of taring is to equalize the weight transmitter output pressures at point of comparison by the differential pressure transmitter. This condition of pneumatic balance is necessary from start to finish of the feeding part of the cycle in order to maintain accurate weigh-proportioning.

Feeding the process at pre-set rate and ratio begins the instant taring is completed at both filled tanks and the sequence switch is indexed to the feed

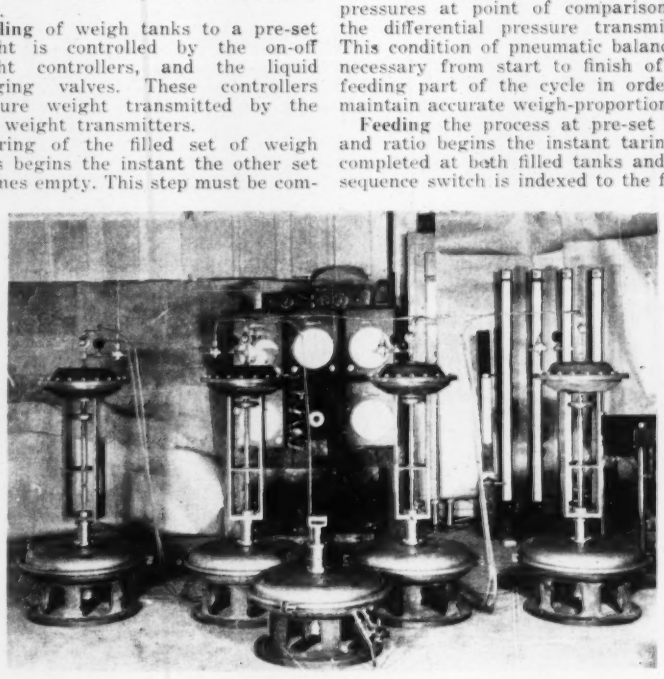


Fig. 9. Shop test of loss-in-weight feeding system.

ng position. The feed rate of the primary liquid is controlled to pre-set value by the time schedule transmitter which pneumatically varies the control point setting of the weight controller. Changes in feed rate are made at the interrupter or by changing the shape and speed of the cam in the schedule transmitter. The weights of the two liquids fed to the process are kept in fixed proportion by throttling the secondary liquid feed valve to maintain a balance of air scale output pressures across the differential pressure transmitter. The proportions of the two liquids in the feed to the process is readily changed by manual adjustment of the ratio relay.

The instrumentation required for this fully automatic control system using air scales is relatively complex. The practicability and economy of the system has been demontrated, however, by one installation in a chemical plant. Because of a desire for highest obtainable proportioning accuracy, some attempts were made to evaluate this point by field tests. One method employed provided for proportioning brine and water into a pipe line and determining the proportioning accuracy from specific gravity readings made on the brine, and on grab samples of the feed mixture, by means of a hydrometer. It was concluded that the proportioning accuracy was at least equal to that of the test facilities provided. The fact that production department personnel using this equipment expressed entire satisfaction with the performance speaks well for the possibilities of pneumatic weighing in process control systems.

Fig. 9 is a photograph of a shop test installation for the loss-in-weight. feeding system. The diaphragm motor heads mounted on the air scales simulate the actual tank loads. Any program of control to be used in the plant may be set up in such a shop test by using the standard instruments specified for the plant installation.

It should be pointed out that this brief discussion hardly scratches the surface so far as the overall field of pneumatic weighing is concerned. The entire time available could well have been devoted to a detailed explanation of only one such system. However, we have attempted to generalize and thereby high-spot practical usage of such equipment. It is likely that I.S.A., and A.S.M.E. will initiate committee work involving application of pneumatic weighing principles in the immediate future. It is our hope that presentation of this brief description of such equipment will create sufficient interest to encourage members of either Society to contribute to this work. In concluding this discussion, let's take a look at some of the practical advantages provided by pneumatic weighing equipment:

1. Enclosed — minimum exposure to corrosive atmosphere
2. Essentially no moving parts
3. No knife edges to wear
4. No explosive hazards
5. Flexibility of application
6. Ease of operation and maintenance
7. Rugged — withstand "shock" load
8. Small space requirement
9. Low cost

Certainly, here is a method of weighing, the use of which promises attractive returns. It merits careful consideration and further exploitation as a needed and useful "tool" in the field of Process Control.

Instruments In Rail Transportation Testing

By DONALD E. CLIFTON *

Simulated service testing of diesel-electric locomotives and their components, although it provides much valuable information, leaves much to be desired. Many operational conditions are impossible to duplicate, for example, extremes of weather or the impacts occuring in actual service. Many times, the operating condition which may be the source of difficulty is unknown or subject only to conjecture. Thus it is apparent that much data must be taken with the locomotive in actual service as the basis for corrective action or development work. During the early history of such testing it was necessary to install the necessary instrumentation within the locomotive itself. Since a locomotive has relatively small unused space, size, portability, and power requirements were major considerations. Test personnel had to make the locomotive their laboratory and home for the duration of the trip—sometimes as long as 48 hours. The effect on instruments and personnel, considering sound intensities at painful levels, temperatures within the locomotive adjacent to the engine or steam generator above 130° F., an so on, may readily be envisioned. The reliability of test data taken under such conditions could well be questioned since the condition under which data is taken is a definite factor in the ultimate reliability of the results, although not necessarily an overwhelming factor.

In view of these undesirable conditions and because of increasing demands for greater magnitude and complexity of instrumentation the test car was constructed. The basic requirements kept in mind during its development were the following:

The physical construction of the car should be such as to permit operation at the high speeds of passenger train operation and also the low speed, high tractive effort operation of freight service.

Adequate living facilities for the test crew should be provided.

An abundance of power should be provided for instrumentation, car lighting, heating and ventilation, refrigeration and cooking and miscellaneous requirements, and in a manner to permit operation independent of a locomotive.

Instrumentation should be based as much as possible on converting the desired measurements to electrical units to permit flexibility in using various instruments for similar measurements.

A Model F-3 booster or "B" unit without any of its regular interior equipment was chosen as the basis for the test car. Its construction would permit high speed operation and the drawbar requirements of heavy freight service. To permit the use of standard 4 wheel trucks the underframe was ballasted to the weight of a standard unit with 9 in. of concrete over the entire deck with equal weight distribution over the trucks being accomplished by carefully located scrap steel in the concrete. The basic 1200 gallon fuel tank and 64 volt battery were included, standard underframe steam piping and both automatic and straight air piping were provided permitting both passenger and freight operation, and a 600 gallon hatch tank normally providing additional boiler water was installed to satisfy water requirements for the car. The basic brake stand was installed in its regular position in the

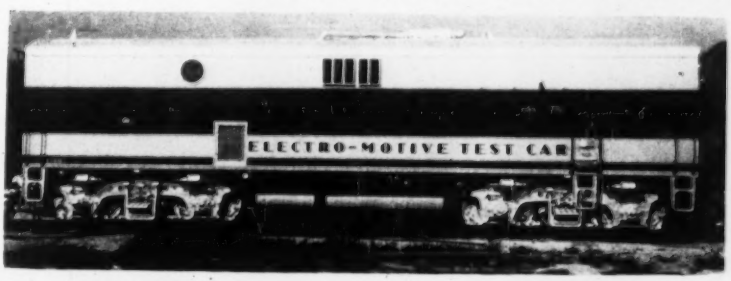


Fig. 1 (Top)

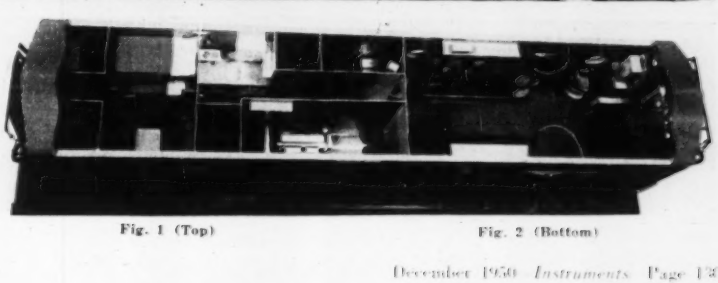


Fig. 2 (Bottom)

* Electromotive Div., General Motors Corp., La Grange, Ill.

NOTE: Presented before the Fifth Annual Convention of the Instrument Society of America, at Buffalo, N. Y., Sept. 12-18, 1950.

right front corner of the car, but all remaining deck space was clear for living quarters, power plant, and test equipment. Insulation and plywood panelling were applied to the interior walls and "V" type bay windows were installed in the instrument end of the car to provide a means of locating the identifying mileposts along the right of way. Two standard open Pullman sections were provided as sleeping facilities. A shower stall and lavatory facilities were provided. Food storage areas and a small refrigerator, electric stove, and various electrical appliances are available for feeding the test crew. The test crew has never utilized dining car service of the train even on extensive test runs. Although all living facilities are compact and somewhat limited, with crews normally working in shifts on long runs, they have proven quite adequite for as many as eight people.

An exterior view of the car is shown in Fig. 1. Fig. 2 is of a model of the test car and shows the location of the instrument room, photographic dark room, power plant, shower, kitchen, berth section, lavatory, and air brake locker.

To provide power for the various requirements of the car an engine driven 220 volt, 3 phase, 60 KW alternator was provided. 220 is used for space heating, cooking, hot water and battery charging. Through transformers 110 is provided for lighting, refrigeration, ventilating fans and miscellaneous requirements. Regulated 110 VAC is provided for all instruments. D-c. voltages required by certain instruments are taken from the battery supply.

Wherever possible the type of primary gaging element used in our field testing is of the type that converts the mechanical phenomena to an electrical quantity. This is done for reasons that are readily apparent and well known; ease of obtaining dynamic response, the facility of obtaining remote indication, and flexibility in the choice of the recording or indicating device. These latter devices in the test car differ basically in their frequency response and their method of indicating or recording.

For the measurement of quantities varying at very slow rates eight potentiometer type instruments are provided, the familiar Leeds and Northrup "Speedomax". The first of these is a 40 point indicator, −50° to 1000° F. The second is a double range 16 point recorder 0° - 400° F. and 0° - 300° C. Four of the remaining instruments are double range 0° - 400° F. and 0° - 300° C. 2 point recorders with a 2 second printing interval. These 6 instruments are used exclusively for temperature indicating or recording. Iron-constantan lead wires are installed in conduit to each end of the car from a central master patch board and terminate in plugs at the end of a length of flexible hose at the ends of the car. Thus thermocouples external to the test car may be connected at the end of the car and at the patch board may be connected at will to any point on any of the temperature indicators or recorders. Of the two remaining instruments one is a double range, 2 point recorder with a 2 second printing interval, one range being 0 - 300° C. and the other being 0° - 30 MV. This latter range is strictly a potential measuring range without temperature compensation and is used for electrical measurements — for example, plotting a cooling curve of an armature by simultaneously plotting the IR drop across a number of bars and the current impressed upon it. The last instrument is a single pen recording potentiometer with a range of −1 to +1 MV again not compensated for temperature. It is used to record the output of a bonded wire strain gage bridge located inside the coupler shank and calibrated in terms of drawbar pull or buff. The instrument is somewhat unusual in that standardizing is accomplished by referring to the voltage applied to the strain gage bridge rather than to a standard cell, and that a low pass filter with a cutoff of less than half a cycle per second is provided between the strain gage bridge and recorder input to eliminate drawbar pull variations occurring at high rates. A great deal of care was taken in choosing gages, in their application and waterproofing and as a result the device is very stable over long periods of time. Fig. 3 and 4 illustrate this instrument installation along with the thermocouple patch board system.

These instruments, although subjected to severe service have given relatively little difficulty. Originally these instruments were shock mounted but severe criticals at certain operating speeds nearly hammered the instruments to bits against the panel openings. Since they have been mounted solidly little difficulty has been encountered other than sorting out a couple of weak vibrators or signal choppers. This was an instance where trying to do a good job worked in reverse.

Some difficulties with the low level potentiometer used with the strain gages were encountered. In all fairness it must be said that some of them resulted from our not knowing exactly what we desired to have. Some instability still exists, but we hope to alleviate this by shielding and removal of some auxiliary apparatus from the interior of the instrument.

A 12 channel recording Hathaway oscillograph is utilized for recording phenomena occuring at rates up to 2000 cycles per second on sensitized paper. This instrument has been used extensively in recording voltages and currents in power and control circuits during switching operations. In conjunction with a Hathaway strain gage control unit it has been used to record the output of strain gages, accelerometers and differential transformers used as motion measuring devices. This control unit is conventional providing carrier power for gaging elements bridge balance provisions, amplification and phase sensitive demodulation and coupling provision to the low impedance galvanometer elements. Fig. 5 illustrates the oscillograph and strain gage control installation. A system similar to the thermocouple installation is incorporated using 4 conductor shielded cable and a patch board system.

This apparatus has functioned well under severe requirements. The unorthodox oscillograph mounting was a space limitation requirement and in this position the tuning fork which is used as the basis for timing lines refused to function in this position but functions well external to the oscillo-

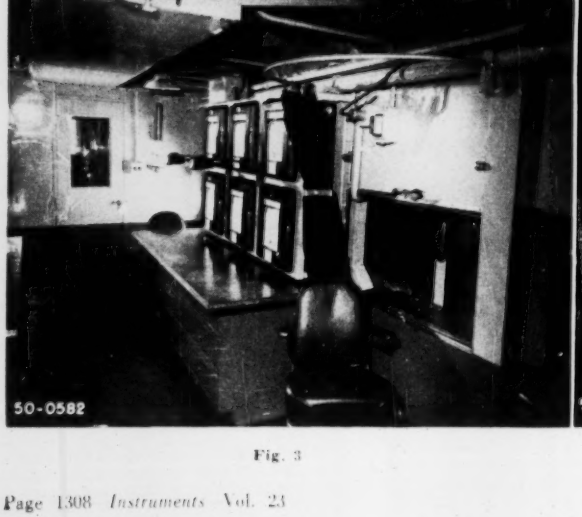


Fig. 3

Fig. 4

graph. Non-linear fuse characteristics in the galvanometer circuit gave some calibration difficulties in electrical investigations. Since replacing these fuses with brass slugs these difficulties no longer exist. Fusing these circuits is much better in theory than in practice since the time lag of the fuse is greater than that of the galvanometer, and effects no protection.

If it were desired to ascertain the peak stress occurring in a structural member during operation it would obviously be impossible to record continuously by means of the recording oscillograph—there being a limitation to the amount of paper that can be processed and analysed. Consequently, an 8 channel selective counting unit was developed for the car which registers on mechanical counters the number of times the phenomena being investigated exceeds certain predetermined levels.

This device includes a 5000 cycle carrier supply for the primary gaging elements. Care was taken to provide good waveform and stability to insure ease and precision in balancing the gaging elements. Balancing of these elements, resistive and reactive, is accomplished in 3 stages of coarse, medium, and fine to eliminate any over critical controls. The voltage amplifier utilizes two high gain rugged duty pentodes utilizing frequency selective feed back and is set up as a passband amplifier, 5000 ± 500 cycles. This alleviates to some extent the 60 cycle pickup usually troublesome in high gain amplifiers and reduces harmonics from the oscillator. Gain control is accomplished between the two stages by a step control and vernier. The output of the voltage amplifier is RC coupled to a power amplifier the output of which is transformer coupled to a full wave rectifier. This rectified voltage is presented to 4 parallel potentiometers through a low pass filter with a 500 cps cutoff. The variable tap on each potentiometer is presented to the input of a triggering circuit. A pentode-triode tube is used and arranged so the pentode input section is biased below cutoff while the triode section is conducting. Upon exceeding a certain input voltage the pentode section begins to conduct and by a cumulative action resulting from the circuit arrangement the combination triggers to the opposed condition—the triode being cut off. As a result the voltage at the plate of the triode rises very sharply. This output is differentiated and the sharp pulse applied to the grid of a thyratron. The thyratron operates with the counter solenoid in its plate circuit. When the counter operates a circuit is completed within the counter applying an oppositely charged condenser to the thyratron plate extinguishing it. The counter completes its cycle and is ready for another pulse. By adjustment of the input potentiometers various relationships may be set up between the counters. A cathode ray oscilloscope and metering means are employed to facilitate balancing and checking of operating voltages. A substitution calibration means is employed wherein a calibrated bridge is inserted in the circuit in place of the measuring element.

Supplemental to this apparatus are provisions to record simultaneously on a recording oscillograph the phenomena presented to the selective counter and a relay section permitting marking a continuous chart when selected counters operate. The frequency response of the counter is limited to approximately 10 cps by the mechanical counters. Fig. 6 illustrates this apparatus.

Our major difficulty has been instability in the triggering portion. Change in tube characteristics with time permit rather wide variations in the voltage at which the circuit triggers. Frequent calibration helps to keep track of these changes but the effect is undesirable. Work at present is toward tubes and circuitry to minimize this effect by arranging a triggering circuit operating on a small voltage change and increasing the biasing voltage.

Despite some shortcomings the device has provided useful data concerning peak operating conditions.

In addition to this major instrumentation continuous records on pen and ink recorders are always run; locomotive speed, air brake applications, throttle positions, dynamic brake applications, and so forth. In addition to these recordings, indicating instruments show the particular operating condition existing. A tachometer is available and a high speed counter utilizing a vacuum tube scaler and mechanical counters is available for registering operating of some chosen device. The recording devices and counters are shown in Fig. 4. Fig. 7, in addition to illustrating the oscillograph and selective counter installation shows the speed indicator, throttle position indicating lights and totalizing clocks, and alarm devices.

During a road test an observer is stationed at the "V" window. At approximately one mile intervals are mileposts or "mile boards" usually a white board with black numbers located on posts or telephone poles. Upon passing these a push button is operated by the observer which operates a marker pen on all recording instruments. Upon analysing the data we then refer to a survey or profile of the railroad on which these mile boards are indicated and thus may determine the operating condition as to curvature and grade at any desired point. These marks on each chart enable tying all records together for a given condition.

An intercommunication system is provided permitting conversation between the test crew in the car to another member in the locomotive. This has proven to be an indispensable aid in all kinds of testing.

In slightly over two years of operation the car has operated in excess of 80,000 miles on major railroads. Test data has been accumulated on motor and motor bearing temperatures, stresses in locomotive axles, stresses in carbody members, voltages and currents in power and control circuits during switching sequences and so forth. Not all of the tests have been in operation on the rails. The test car was located on a siding and utilized to record stresses in light branch line rail under various locomotives and on another occasion to study engine operation at altitudes from 600 to over 10,000 ft.

The car has satisfied a major need in providing a means of collecting data in railroad operation with instrumentation and crew facilities far superior to those available before its construction. It has provided basic data for design and development work and expedited trouble shooting. Demands for its services are constantly on the increase. Instrumentation has been, on the whole, satisfactory, but much development work is still in progress. It is felt that the expense and efforts required to build, maintain and operate such a car have been well justified.

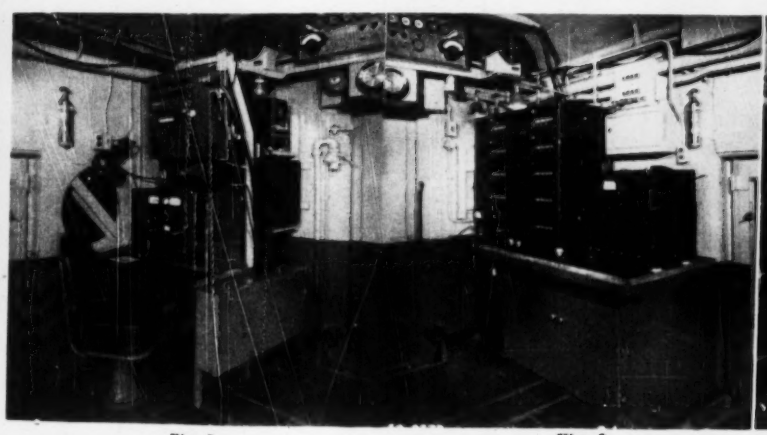


Fig. 5.

Fig. 6

Fig. 7

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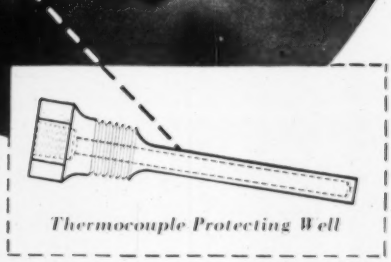

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Calculation *of* Orifice Meter Coefficients *for* Natural Gas

By GEORGE H. FORSTER, JR., The Texas Company

PAPER No. 1 of the Southern California Meter Association's Meter Course covered (a) Fundamental Gas Laws and Their Application to Orifice Metering; (b) Fundamentals of Orifice Meter Measurement. The basic gas laws pertaining to orifice meter measurement and the necessity of applying correction factors for each and every gas being measured were given. The correction factors are necessary of course, to express the quantity of Natural gas being measured through an orifice meter in terms of standard cubic feet, defined as follows: A standard cubic foot of gas is that quantity of gas which, at a temperature of 60 F. and an absolute pressure of 14.73 psi. occupies one cubic foot.

All of our present tables and equations used in the State of California, give results in this unit.

As this paper is dealing with coefficients, the definition of a coefficient as it pertains to orifice meter measurement follows: The coefficient is part of the orifice meter formula that may, when the data of the meter set-up are known, be condensed into a single numerical quantity and, in this simple form, be used repeatedly, so long as the data of which it is composed are unchanged; and is the amount of gas, in Standard cubic feet, which will pass through an orifice in one hour at one pound absolute pressure and at one inch water differential.

This equation is written

$$Q = C' \sqrt{(hP_2)}$$

where C' = Coef. corrected;

h = differential in inches of water;
P_2 = absolute pressure (downstream of orifice plate).

We are indeed fortunate that the groundwork has been done, tables prepared and even further simplified to the extent that coefficient calculations are a very simple procedure.

The Basic Standard Natural Gas Hourly Coefficients (C), both Flange Connections and Pipe Connections, are published for Standard sized orifices in Standard sized tubes. The basic coefficients are at a pressure base of 14.73 psi., an absolute temperature of 520 F. and a specific gravity value of 1.00 (air). California Natural Gasoline Association Bulletins TS 353 and TS 402 Southern California Meter Association Handbook of Data Sheets.

Besides standardizing on these factors, two more assumptions had to be made. One is that the value of $\sqrt{(hP_2)}$ is infinite, i. e., the Reynolds number is infinite, and the other that h/P_2 is zero, i. e., no expansion throughout the flow range. Of course, corrections of these two conditions are made on actual flow conditions.

For odd sized orifices or odd sized tubes, compute (C), from the equation

$$C = d^2ZL$$

where:

$Z = 338.2\ K_{(c)}$

$L = K_{(c)}\ K_{(c)}$

Tables for Z and L are given for both Flange and Pipe Connections.

Computation of C'—corrected coefficient for flowing conditions.

$$C' = C \times F_G \times F_T \times F_{PV} \times F_{c2} \times F_R$$

C = Basic coefficient (just discussed)

F_G = Specific Gravity Factor $\sqrt{(1.000/G)}$

F_T = Flow Temperature Factor $\sqrt{\dfrac{460+60}{460+\text{observed temp.}}}$

F_{PV} = Superexpansibility factor $\sqrt{Y}$

C.N.G.A. Bulletin TS-354 gives factors for this correction, based on experimental data, and it is a function of specific gravity, temperature and absolute pressure; for deviation from Boyle's Law and Charles' Law.

F_{c2} = Expansion Factor (From Tables)

This factor depends on the value of Beta, that is, the ratio of orifice diameter to actual pipe diameter d/D, and on the ratio of the differential pressure to the static pressure, h/P_2.

F_R = Reynolds Number Factor

$$1 + \frac{S}{\sqrt{(hP_2)}}$$

Obtain S from Tables

(S remains constant for any given orifice and pipe size)

The Reynolds factor varies with Beta, pipe diameter and the Reynolds Number. The Reynolds number varies with the velocity—orifice diameter—density and viscosity, with density and viscosity assumed to be constant.

Both the F_{c2} and F_R Factors differ for Pipe and Flange Connections requiring tables for each type of connection.

For Tables—Nomenclature—and constants used in Tables, refer to C.N.G.A. Bulletin TS-353 and/or S.C.M.A. Data Sheets 193 to 208, inc. Also C.N.G.A. Bulletin TS-354 for Superexpansibility Factors. For Derivation of Orifice Meter Flow Formula for Gas—see S.C.M.A. Data Sheet 153.

One additional factor shall be applied to the equation for correcting for C' and that is, the factor for Meter Differential Range and Spring Range when square root charts are used. This factor has the symbol M and follows C in the sequence.

$$M = 0.01 \sqrt{(R_h R_p)}$$

SAMPLE PROCEDURE—REGULAR CHARTS

Given Conditions

Flange Connections—50# Spring 50 in. Meter

6" line (6.025) —2.75 in. orifice

Specific Gravity 0.915—Flow Temperature 85 F

Differential Pressure 33 in. Static Pressure (P_2) 18 psig.

(C.N.G.A. Bulletin TS-353)

C from Table 1 = 1571.8

F_G from Table 13 = 1.0454

F_T from Table 14 = 0.9768

F_{PV} from C.N.G.A. Bulletin TS-354 = 1.0029

January Meeting: Thursday the 18th, Rio Hondo Country Club, Downey, Calif. Dinner at 6:30. Meeting at 8:00 p.m.

Feature: "Nuclear Energy for Peace and War" by Dr. Albert W. Bellamy, Prof. of Zoology and Biophysics, University of California.

Table A-5 factor for 0.915 S.G.—85F. —100 psia.+1.0163

18# ga.+14.73 = 32.73 psia. Factor sub Table F′ = 0.1791

0.0163 x 0.1791 = 0.0029+1 = 1.0029

F_{pv} from Table 6 = 1.0063

$$\text{Beta} = \frac{2.75}{6.25} = 0.45$$

$$\frac{h}{P_2} = \frac{33 \text{ in.}}{18+14.73} = \frac{33}{32.73} = 1.0$$

F_R from Table 4 = 1.0009

S(6.065 by 2.75) = 0.030

$\sqrt{(hP_2)} = \sqrt{[33 \times (18+14.73)]} = 32.86$

$$1+\frac{S}{\sqrt{(hP_2)}} = 1+\frac{0.030}{32.86} = 1.009$$

C′ = 1571.8 x 1.0454 x 0.9768 x 1.0029 x 1.0063 x 1.0009

= 1621.4 hourly coefficient

$Q = C'\sqrt{(hP_2)}$

= 1621.4 x $\sqrt{[33(18+14.73)]}$

= 1621.4 x 32.86

= 53 MCF per hour

Sample Procedure—Square Root Charts

Given Conditions

Same as for Regular Charts except that chart readings will be in square root of 33 in. diff. and of 18 psig.+14.73 abs., or 8.12 diff. and 8.09 static for 50≠50in. meter.

C from Table 1 = 1571.8

M from Table 16 = 0.5000

F_G from Table 13 = 1.0454

F_T from Table 14 = 0.9768

F_{PV} from C.N.G.A. Bulletin TS-354 = 1.0029

Table A-5 factor for 0.915 S.G.—85F.—100 psia. = 1.0163

Static 8.09² x 0.5000 = 32.73 psia.

Factor Sub Table F′ = 0.1791

0.0163 x 0.1791 = 0.0029+1 = 1.0029

F_{pv} from Table 6 = 1.0063

$$\text{Beta} = \frac{2.75}{6.075} = 0.45$$

$$\frac{h_w}{P_2} = \frac{8.12}{8.09} = 1.0 \text{ refer to Table 15}$$

1.0 h p for 50≠50 in. meter = 1.0 for use in Table 6

F_R from Table 4 = 1.0009

S(6.065 x 2.75) = 0.030

Mh_wP_2 = .5000 x 8.12 x 8.09 = 32.84

$$1+\frac{S}{Mh_wP_2} = 1+\frac{0.030}{32.84} = 1.0009$$

C′m = 1571.8 x 0.5000 x 1.0454 x 0.9768 x 1.0029 x 1.0063 x 1.0009

= 810.6 hourly sq. root coef.

$Q = C'Mh_wP_2$

= 810.6 x 8.12 x 8.09

= 810.6 x 65.69

= 53 MCF per hour.

For convenient reference on Standard Procedure for Computing Coefficients and Charts for Gas—See S.C.M.A. Data Sheet 153A.

One can see from the detail work necessary, that many coefficient calculations, although fairly simple, can be very tedious. The C.N.G.A., The Pacific Gas Association and The Southern California Meter Association, through a joint committee went to work to simplify the coefficient calculation procedure.

In 1941, the work of this committee appeared as C.N.G.A. Bulletin Ts-402 and quoting from the preface "The metnod presented involves no basic change from the original data, but affects only that part of the procedure pertaining to the application of the correction factors. Simplicity in the application of these correction factors has been accomplished by

1) Establishing a new sequence for the application of the correction factors, setting the most variable factors at the end of the computation sequence.

2) Combining the original Reynolds and Expansion factor correction tables into a single table requiring only one reference.

3) Introducing a combination temperature and specific gravity table.

4) Including a simplified tabulation of the superexpansibility tables developed in C.N.G.A. Bulletin TS-354 to eliminate the necessity of an outside reference for this correction factor."

This manual is a work manual, while C.N.G.A. Bulletin Ts.—353 still remains as the basic text book for coefficient calculation here on the Pacific Coast.

We shall now calculate a coefficient, the simplified way, using the same given conditions as before.

Regular Charts

Coefficient Record — Type Connection

h	h/P₂	Ext. Group	Line and Orifice	Meter Range		Gage Press.	Gravity	Temp.	
Pres. lb. ga.	Beta	S Group	C		$F_{pv}^2F_R$	F_{PV}	F_GF_T		C′
Given Conditions								*Flange*	
33.0			6 x 2.750	50≠50in.		18.0	0.915	85	
18.0									
Found									
	1.0	7							
	0.45	(1)	1571.8		1.007	1.003	1.022		1622.4

Table I 50# Spring 50 in. h/P_2 = 1.0 Ext. group = 7

Table II F Beta = 0.45—S group-= 1—C = 1571.8

Table III F $F_{pv}^2F_R$ = B(0.45) to h/P_2 (1.0) down to Ext. group (7) at S group (1) = 1.007

Table IV F_{PV} at 60F. = 0.910 at 15≠ = 1.004

Table IV T—F_{PV} at 85 F. = 1.004 at 60 to 1.003 at 85 F.

Table IV Sp. Gr. & Temp. Factor 0.915 at 84F. = 1.022

C′ = C x $F_{pv}^2F_R$ x F_{PV} x F_GF_T = 1571.8 x 1.007 x 1.003 x 1.022 = 1622.4

Q = C′ x $\sqrt{[33 \times (18+14.73)]}$ = 1622.4 x 32.86 = 53 MCF per hour

Square Root Charts

Coefficient Record — Type Connection

h_w	h_w/P_2	Ext. Group	Line and Orifice	Meter Range		Gage Press.	Gravity	Temp.	
P_{w2}	Beta	S Group	C	M	$F_{pv}^2F_R$	F_{PV}	F_GF_T		C′
Given Conditions								*Flange*	
8.12			6 x 2.750	50≠50in.			0.915	85	
8.09									
Found									
	1.0	7				15.0			
	0.45	(1)	1571.8	0.5000	1.007	1.003	1.022		811.3

Table I 50≠ Spring 50 in. gage $h_w P_{w2}$ = 1.0—Ext. Group = 7—M = 0.5000—Ga Press. = 15≠

Balance same as for Regular Charts

C′ = C x M x $F_{pv}^2F_R$ x F_{PV} x F_G x F_T

1571.8 x 0.5000 x 1.007 x 1.003 x 1.022 = 811.3

Q = C′ x h_w x P_{w2} = 811.3 x 8.12 x 8.09 = 811.3 x 65.69 = 53 MCF per hr.

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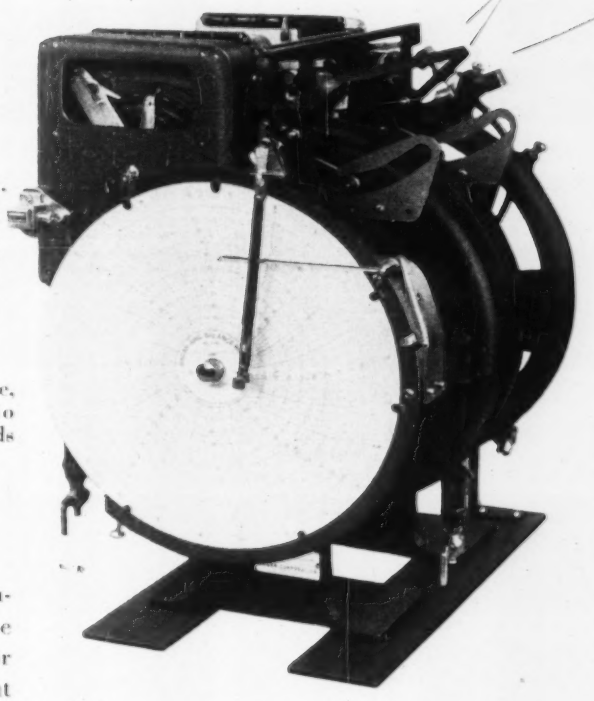

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Manufacturers' New Literature

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Requests for literature FROM ABROAD should be made on company letterhead and mailed DIRECTLY to the manufacturers.

S-738 HIGH-RANGE PRESSURE TRANSDUCERS. 4-page Bulletin 3.1—Section B describes maker's high-range pressure transducers; covers features, applications, specifications, and dimensional diagrams.—Statham Laboratories, 9328 Santa Monica Blvd., Beverly Hills, Calif.

S-739 UNIVERSAL WEAR TESTER. 4-page bulletin describes and illustrates maker's "CSI-Stoll-Quartermaster" universal wear tester for quantitatively measuring resistance to flat, edge, and flex abrasion; covers features, operation, specifications.—Dep't S, Custom Scientific Instruments, Inc., P. O. Box 170, Arlington, N. J.

S-740 SUBMINIATURE TUBES. 6-page bulletin contains characteristics chart of 30 of maker's subminiature electron tubes and suggestions for mounting, shielding, and application to obtain maximum life; covers dimensions, lead spacings, and base diagrams.—Sylvania Electric Products Inc., Emporium, Penna.

S-741 COMPRESSED GASES & GAS REGULATORS. 16-page folder lists 74 rare and common gases with gas and cylinder price list and cylinder sizes; covers automatic flow regulators, controllers and accessories.—The Matheson Co., Inc., East Rutherford, N. J.

S-742 "THE OHMITE NEWS." 2-page July-August 1950 issue of this house organ features article on application of maker's "Model J" rheostats in an automatic steering unit for watercraft; also items on uses of maker's resistors and voltage dividers.—The Ohmite Co., 4835-41 Flournoy St., Chicago 44, Ill.

S-743 BATTERY CHARGING, ANALYZING, TESTING. Five bulletins describe and illustrate maker's battery charging, analyzing, and testing equipment. "A-50" covers maker's "Batteryscope" for checking condition, state of charge and cable connections in one operation. "A-50-1" covers "Chargalyzer" fast battery charger and analyzer. "A-50-2" covers self-regulating fast charger. "A-49-1" covers complete line of chargers, testers and accessories. "1-50" covers d-c. power supplies, with specifications for aircraft, general, battery-charging, d-c. arc lamp, and electroplating and battery-charging types.—McColpin-Christie Corp., Ltd., 3410 W. 67th St., Los Angeles 43, Calif.

S-744 PRECISION LEVELS. 6-page bulletin illustrates and describes maker's "All-Way" precision levels and plumb-levels; covers features, typical applications, specifications.—Wm. B. Fell Co., 320 McLain Ave., Rockford, Ill.

S-745 RADIOACTIVITY MEASUREMENT. 4-page Bulletin 14 pictures and describes maker's "Model A-4" radioactivity scaler; also describes new laboratory facilities and nation-wide representation.—Radioactive Products, Inc., 443 W. Congress St., Detroit 26, Mich.

S-746 VACUUM-TUBE VOLTMETER. 2-page bulletin illustrates and describes maker's "MV-73B Multimeter" vacuum-tube voltmeter for high-sensitivity and r-f. measurements; covers features, advantages, specifications.—Millivac Instruments, P. O. Box 3027, New Haven, Conn.

S-747 GEARMOTORS. 4-page Bulletin B250 describes and illustrates maker's right-angle type single- and three-phase gearmotors; covers construction features, specifications, and prices; contains dimension table and diagram.—Abart Gear & Machine Co., 4828-4836 W. 16th St., Chicago 50, Ill.

S-748 OSCILLOSCOPE. 2-page bulletin illustrates and describes maker's "Model T-601-A" wide-band high-gain oscilloscope; covers characteristics, features, and specifications.—Television Equipment Corp., 238 William St., New York 7, N. Y.

S-749 D.C.-A.C. CHOPPER. 2-page Catalog 246B describes and illustrates maker's d.c.-a.c. 60-cps chopper; covers features, specifications.—Stevens-Arnold Inc., 22 Elkins St., South Boston 27, Mass.

S-750 HAND TACHOMETERS. 6-page Bulletin 35-01 illustrates maker's "Jagabi Type DO and AO" hand tachometers; covers features and specifications.—James G. Biddle Co., 1316 Arch St., Philadelphia 7, Penna.

S-751 HYDRAULIC MOTOR VALVE. 4-page Bulletin 1080-A describes and illustrates maker's "Type O" hydraulic motor valve in single- and double-seated models; covers principle of operation, prices and operating pressures, construction details, capacities.—Sarco Company, Inc., Empire State Bldg., New York 1, N. Y.

S-752 RECEIVING TUBE MANUAL. 324-page "RC-16" edition of maker's receiving tube manual contains sections on electrons, electrodes, and electron tubes; electron tube characteristics, applications, and installation; interpretation of tube data; receiving tube classification chart; tube types—technical data; electron tube testing; resistance-coupled amplifiers; circuits; and outlines. Price 50 cents.—Commercial Engineering, RCA Tube Department, Harrison, N. J.

S-753 CARBON DETERMINATION APPARATUS. 4-page Bulletin 319 illustrates and describes maker's "Combustron" carbon determination apparatus; covers features, construction, specifications, and table of typical determinations.—Burrell Corp., 1942 Fifth Ave., Pittsburgh 19, Penna.

S-754 INSTRUMENT GEARBOX. 2-page bulletin describes and illustrates maker's "Hi-Reduction" instrument gearbox; covers features, specifications, construction.—Link Aviation, Inc., Binghamton, N. Y.

S-755 BUNSEN BURNER. 4-page folder illustrates and describes maker's "Touch-O-Matic" on-off Bunsen burner; covers features, operation.—Hanau Engineering Co., Inc., 1233 Main St., Buffalo 9, N. Y.

S-756 HIGH-PRESSURE FLOWMETERS. 10-page Catalog Section 40 illustrates and describes maker's armored "Flowrator" high-pressure flowmeters; covers features, construction, operation; contains dimension tables and capacity guide.—Fischer & Porter Co. Hatboro, Penna.

S-757 LABORATORY MIXER. 2-page bulletin illustrates and describes maker's hand-operated utility mixer; covers features, advantages, ordering data, accessories.—Claud S. Gordon Co., Chicago 16, Ill.

S-758 CALIBRATING STANDARD. 4-page Bulletin TP-32-A describes and illustrates maker's calibrating standard for pressure instruments; covers operation, design, features, and specifications.—Wallace & Tiernan Products, Inc., Belleville 9, N. J.

S-759 SAND WASHER. 2-page bulletin illustrates and describes maker's sand washer for removal of clay from sand grains; covers features, operation, specifications, ordering data and accessories.—Claud S. Gordon Co., Chicago 16, Ill.

S-760 DRY-ICE STORAGE CABINETS. 4-page bulletin illustrates and describes maker's

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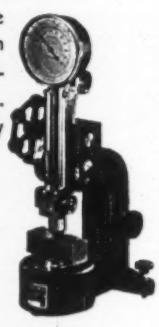

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dry-ice storage cabinets for laboratory storage requirements of -60 C. or lower; covers features, construction, sizes and models available. —Dep't D, Custom Scientific Instruments, Inc., P. O. Box 170, Arlington, N. J.

S-761 "CENCO NEWS CHATS." 28-page No. 69, Autumn 1950 issue of this house organ fentures articles titled "The Institute of Radio Engineers," "Photomicrography within Easy Reach"; also items on maker's scientific apparatus (multi-range fluorimeter, cartesian manostat, cathode-ray oscilloscope, etc.).—Central Scientific Co., 1700 Irving Park Rd., Chicago 13, Ill.

S-762 PRESSURE MEASUREMENT. 8-page folder describes and illustrates maker's "Pressuregraph" and "Syncro-Markers" instruments for pressure-time studies of internal combustion engines, compressors, injection pumps, etc.; also covers maker's "Dynamic Micrometer" for measuring dynamic or static displacement, vibration or movement of any metal body.—Electro Products Labs., Inc., 4501 N. Ravenswood Ave., Chicago 40, Ill.

S-763 "BURRELL ANNOUNCER." 16-page No. 50-10-40 issue of this house organ features article titled "Metallographic Sample Preparation"; also describes laboratory apparatus (recirculating pumps, metallographic equipment, induction heater, static eliminators, bone decalcifier, etc.); also encloses bulletin on "International" dual-purpose laboratory centrifuge, and bulletin on "Castaloy" laboratory appliances.—Burrell Corp., 2223 Fifth Ave., Pittsburgh 19, Penna.

S-764 CHEMICAL PORCELAIN. 8-page Bulletin 299 describes and illustrates use of maker's chemical porcelain on valves, pipe and fittings, centrifugal pumps and pumping heads, etc.; gives features, characteristics, sizes, operation, specifications; also covers "Pulsafeeder" piston-diaphragm proportioning pumps.—Lapp Insulator Co., Inc., Le Roy, N. Y.

S-765 REGULATORS. 4-page bulletin illustrates and describes maker's temperature and pressure regulators, desuperheaters, self-cleaning strainers; covers features and operation.—Spence Engineering Co., Inc., Walden, N. Y.

S-767 LIQUID PROPORTIONING PUMPS. 8-page Bulletin 262 describes and illustrates maker's "Pulsafeeder" piston-diaphragm proportioning pumps for controlled-volume pumping; covers operation, features, construction, sizes and ratings, typical applications.—Lapp Insulator Co., Inc., Le Roy, N. Y.

S-768 VIBRATION TESTER. 4-page Bulletin 4101 illustrates and describes maker's "Model 44 Shaker" vibration test equipment; covers features, installation and performance data; also covers "Model 45" power supply.—The Calidyne Co., 751 Main St., Winchester, Mass.

S-769 ILLUMINATION RECORDER. 2-page Instrumentation Data Sheet 9.1-5 illustrates and describes Gardner Laboratories' "Illuminometer" illumination recorder utilizing Brown "ElectroniK" strip-chart recording potentiometer; covers application, installation, features and performance data.—Industrial Div., Minneapolis-Honeywell Regulator Co., Philadelphia 44, Penna.

S-770 RATIO TOTALIZER. 8-page Bulletin 5450 illustrates and describes maker's pneumatic ratio totalizer and function generator for combining input control pressures and spring forces to produce single output control pressure; covers principle of operation, construction, typical applications, features and characteristics.—Hagan Corp., Hagan Bldg., Pittsburgh 30, Penna.

S-771 GLOSSMETER. 2-page bulletin illustrates and describes maker's 60-degree glossmeter; covers features, accuracy, price.—Henry A. Gardner Laboratory, Inc., 4723 Elm St., Bethesda 14, Md.

S-772 ELECTRICAL INSTRUMENTS. 8-page bulletin illustrates and describes maker's low power factor wattmeters, moving iron a-c. instruments, dynamometer instruments, and a-c. "Poly-ranger" for a-c. and d-c. measurement; covers features, specifications, and ranges.—Sensitive Research Instrument Corp., 9-11 Elm Ave., Mount Vernon, N. Y.

S-773 X-RAY PHOTOMETER. 8-page Bulletin GEC-412A illustrates and describes maker's x-ray photometer for chemical analysis by x-ray absorption; covers advantages, applications, table of sensitivities, theory of operation, and speci-

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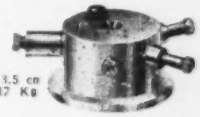

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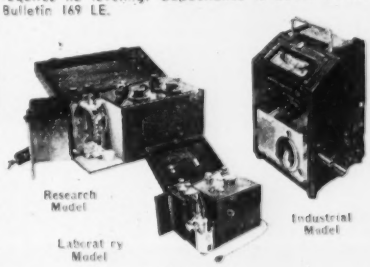

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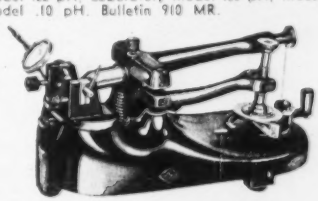

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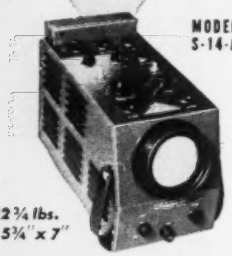

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fications.—Apparatus Dep't, General Electric Co., Schenectady, N. Y.

S-774 CIRCUIT CONTROLLING COUNTERS. 4-page Bulletin 202 describes and illustrates maker's "Cyclo-Monitors" circuit controlling pre-set counters with automatic reset; covers uses, specifications, and general characteristics on models for mechanical and electric counting. —Counter and Control Corp., 5225 W. Electric Ave., Milwaukee 14, Wis.

S-775 DATA BOOK AND CATALOG. 42-page Bulletin TC-8, 1950 edition of Data Book & Catalog illustrates and describes, with full specifications, maker's instrument sensing units and accessories; covers base metal, noble metal, and special purpose thermocouples, resistance bulbs and radiation detectors, components and accessories. Contains data on making, checking, selecting and ordering thermocouples; also wire sizes and resistances and temperature-millivolt curves.—Wheelco Instruments Co., 847 W. Harrison St., Chicago 7, Ill.

S-776 SOLDERING GUNS. New catalog covers complete line of maker's soldering guns for every requirement; contains data helpful to TV and radio technicians, electricians, etc.; gives detailed descriptions and lists prices.—Weller Electric Corp., Easton, Penna.

S-777 SOLDERING GUIDE. 20-page pocket-size brochure titled "Soldering Tips—Your Guide to Easier Soldering" gives illustrated step-by-step rules to follow for sound soldering. Price 10 cents.—Weller Electric Corp., Easton, Penna.

S-778 ELECTRONIC FLASH LIGHT METER. 8-page Vol. 25, No. 5 issue of "The General Radio Experimenter" features articles titled "Light Meter for Electronic Flash Photography," and "A 'Variac' Phase-shift Circuit"; covers specifications on "Type 1501-A" light meter and "1501-P1" probe. Bulletin of new instruments announced since publication of Catalog L also enclosed.—General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

S-779 RESISTORS, VOLTAGE REGULATORS, ETC. 20-page catalog illustrates and describes maker's resistors, voltage regulators, composition-element controls, output attenuators, power resistor decade box, power rheostats, rotary switches, etc.; covers features, specifications, prices.—Clarostat Mfg. Co., Inc., Dover, N. H.

S-780 SPOT ILLUMINATOR. 6-page folder illustrates and describes pocket-size "Lumi-Scope" spot illuminator for illuminating parts or objects normally inaccessible to ordinary light source; covers features, uses, price.—Henry A. Gardner Laboratory, Inc., 4723 Elm St., Bethesda 14, Md.

S-781 RESISTORS. 2-page September 1950 issue of "The Ohmite News" features article on use of maker's resistors in Remington Rand "Robot Kardex" record-keeping unit; also contains items on tapped or multi-section resistors, r-f. chokes, rheostats.—Ohmite Mfg. Co., 4835-41 Flournoy St., Chicago 44, Ill.

S-782 ILLUMINATED PANELS. 8-page folder gives features and advantages of maker's plastic-fabrication method for manufacturing illuminated control panels, dials, knobs and switchboard assemblies.—Universal Aviation Corp., 230 Park Ave., New York 17, N. Y.

S-783 INSTRUMENTATION DATA SHEET. 4-page Instrumentation Data Sheet No. 10.14-4 contains illustrated article titled "Smoke Prevention Plus Combustion Control Cut Fuel Costs"; also illustrates and describes maker's "ElectroniK" standard speed potentiometer.—Industrial Div., Minneapolis-Honeywell Regulator Co., Philadelphia 44, Penna.

S-784 RADIOACTIVITY MEASUREMENT. 48-page Information Bulletin No. 10 illustrates and describes maker's instruments and accessories for radioactivity measurement (a complete basic radiochemical lab., scalers, nucleometers, anthracene crystals, absorbers, shields, carts and protective clothing, etc.)—Radiation Counter Labs, Inc., 1844 West 21st St., Chicago 8, Ill.

S-785 TEMPERATURE MEASUREMENT IN AIRCRAFT. 12-page bulletin illustrates and describes maker's instruments and accessories for measuring temperatures in aircraft (resistance thermometers, resistance bulbs, thermocouple thermometers, thermocouples, hermetically sealed temperature indicators, thermocouple lead-wire, accessories, thermometer testers, indicating pyrometers, pyrometer potentiometers, etc.).—The Lewis Engineering Co., Naugatuck, Conn.

S-786 ELECTROSCOPES. 4-page bulletin illustrates and describes maker's Lauritzen quartz fiber electroscopes for physicists, biologists, chemists, radiologists; covers features, uses, accessories.—Fred C. Henson Co., 3311 E. Colorado St., Pasadena, Calif.

S-787 COMBUSTION CONTROLLER. 4-page Bulletin 802 describes and illustrates maker's "Hazegage" photoelectric combustion controller; covers use, operation, advantages, installation, specifications.—Ess Instrument Co., Bergenfield, N. J.

S-788 SMOKE AND COMBUSTION INSTRUMENTS. 8-page Bulletin 501 describes and illustrates maker's smoke and combustion control instruments; covers typical installations, operation, also potentiometer and operation recorders.—Ess Instrument Co., Bergenfield, N. J.

S-789 INDUSTRIAL COLOR TV. 16-page Bulletin covers maker's "Model TA-161A" industrial color television system for non-broadcast, wired industrial applications; illustrates applications (medical-surgical, industrial, research & development, merchandising); discusses features, method of use, and components.—Television Transmitter Div., Allen B. Du Mont Labs, Inc., 1000 Main Ave., Clifton, N. J.

S-790 FLOW MEASUREMENT. 8-page Bulletin 11C4 describes and illustrates maker's flowmeters, indicators, and recorders; covers features, construction, applications, and accessories.—Barton Instrument Corp., 1429 So. Eastern Ave., Los Angeles 22, Calif.

S-791 DIAL INDICATORS & GAGES. 84-page Catalog 50 illustrates and describes maker's line of dial indicators and dial gages for measuring and comparing linear dimensions; covers features, specifications and prices.—Federal Products Corp., 1144 Eddy St., Providence 1, R. I.

S-792 SNAP-ACTION SWITCH CONVERSION CHART. Conversion chart shows AN numbers and maker's corresponding types; is pictorially indexed with outline drawings of switches used in aircraft and other applications. —Unimax Switch Div., The W. L. Maxson Corp., 460 W. 34th St., New York 1, N. Y.

S-793 MERCURY CATHODE APPARATUS. 32-page Working Manual illustrates and describes maker's "Dyna-Cath" high-speed magnetic mercury cathode apparatus; covers performance, construction, operation, applications, and working methods.—Eberbach & Son Co., Ann Arbor, Mich.

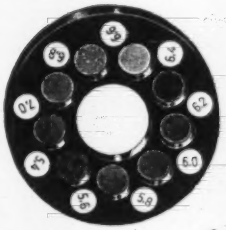
S-794 ELECTRON TUBE MANUAL. 52-page engineering manual and catalog on gaseous discharge rectifier and control-rectifier tubes covers ratings, applications, life expectancy, tube protection efficiency, regulation, filters, load, mechanical design and variations; also includes complete line of maker's tubes with illustrations and specifications.—Electrons, Inc., 127 Sussex Ave., Newark 4, N. J.

S-795 INSTRUMENT TRANSFORMERS. 76-page Bulletin GET-97A "Manual of Instrument Transformers—Operation principles and Application Information" covers basic fundamentals and gives complete data on potential and current transformers (operating principles, types and ratings, applications, circuits, fusing, etc.); also contains chart for selecting proper transformers for specific application. Price is $1.00.—Apparatus Dep't, General Electric Co., Schenectady 5, N. Y.

S-796 INSULATION TESTERS. 2-page bulletin illustrates and describes maker's a-c. and d-c. insulation testers; covers features, applications, operation, specifications.—Cole Instrument Co., 1320 S. Grand Ave., Los Angeles 15, Calif.

S-797 OPTICAL-POINTER-TYPE INSTRUMENTS. 2-page bulletin illustrates and describes maker's large optical pointer type instruments; covers application, ranges, accuracy, construction, dimensions; also covers maker's electrostatic voltmeters including ranges and prices.—Cole Instrument Co., 1320 S. Grand Ave., Los Angeles 15, Calif.

S-798 CONTROLLED-VOLUME PUMP. 2-page Bulletin MP-50 illustrates and describes maker's "miniPump" controlled-volume pump for handling minute quantities of clear liquids; covers features, models available, pressure capacities.—Milton Roy Co., 1300 E. Mermaid Lane, Philadelphia 18, Penna.



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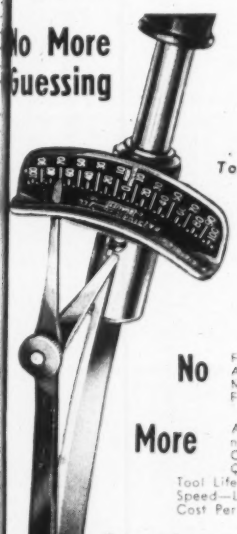

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S-799 AUTOMATIC RECORDERS. 4-page Bulletin 950, "The Graphic," features article titled "Let's Look at the Record—Industrial Production Monitored by Automatic Recorders" describes use of maker's operation recorders in production of automobile inner tubes.—The Esterline-Angus Co., Inc., P. O. Box 596, Indianapolis 6, Ind.

S-800 INDUSTRIAL CHILLING EQUIPMENT. 18-page bulletin illustrates and describes maker's laboratory & hospital chilling unit, industrial sub-zero unit and cascade sub-zero chilling machine; covers features, specifications, applications, technical data and tables.—Sub-Zero Products Div., Deepfreeze Distributing Corp., 3928 Reading Rd., Cincinnati 29, Ohio.

S-801 pH ELECTRODES. 28-page Catalog EN-53 describes, illustrates and lists maker's line of pH electrodes—assemblies, parts and accessories; also describes and illustrates instruments for measuring pH.—Leeds & Northrup Co., 1907 Stenton Ave., Philadelphia 44, Penna.

S-802 INSTRUMENT CASES. 4-page folder illustrates and describes several types of maker's cases for instruments, tools, dies, etc., to "dress up" product and protect against dust, dirt and breakage.—Warwick Products Co., 5020 Euclid Ave., Cleveland 15, Ohio.

S-803 INSTRUMENT METAL TUBE FITTINGS. 4-page bulletin illustrates and describes maker's "Swagelok" metal tube fittings; covers features, installation, types and sizes.—Crawford Fitting Co., 21850 St. Clair Ave., Cleveland 17, Ohio.

S-804 COMBUSTION CONTROL. 16-page Bulletin 102-E describes and illustrates maker's air-operated combustion controllers; covers principles, application, pilot valves, air supply, etc.—Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

S-805 ELECTRONIC INSTRUMENTS. 12-page Bulletin 231-A describes and illustrates maker's electronic instruments for temperature pressure, flow and other factors (recorders, indicators, recorder-controller, indicator-controller, integrators); covers features, application, measuring circuits, temperature.—Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

S-806 LABORATORY GRINDING MILLS. 6-page bulletin illustrates and describes maker's laboratory mills; covers construction and operating features, prices; also covers laboratory carts, heavy movable table, and apparatus for protein, solvent extractions, and crude fiber determinations.—Laboratory Construction Co., 1115 Holmes St., Kansas City, Mo.

S-807 SELENIUM RECTIFIER CARTRIDGES. 2-page bulletin illustrates and describes maker's high-voltage selenium rectifier cartridges; covers typical applications, standard cell sizes, types available.—International Rectifier Corp., 6809 S. Victoria Ave., Los Angeles 43, Calif.

S-808 SMOKE DENSITY RECORDERS. 2-page bulletin describes and pictures "Sentry" smoke density recorders; covers features, models available, operation, typical results.—L. V. Edwards, 32 Irving Place, Rockville Centre, N. Y.

S-809 ORIFICE FLANGE UNIONS, SEAL CHAMBERS. 16-page Bulletin 503 describes and illustrates maker's forged steel orifice flange unions (slip-on, threaded, welding neck, socket type welding) and seal chambers; covers features, sizes, specifications, dimensions.—Taylor Forge & Pipe Works, P. O. Box 485, Chicago 90, Ill.

S-810 RECORDER-CONTROLLER. 16-page Bulletin 381 describes and illustrates maker's "Model 40" automatic recorder-controller; covers design and construction features; applications, operation.—The Foxboro Co., Foxboro, Mass.

S-811 HIGH-SPEED SCALER. 4-page Vol. 2 No. 2 issue of the "hp JOURNAL" features article on maker's "Model 520A" high-speed scaler titled "A 10 MC Scaler for Nuclear Counting and Frequency Measurement"; includes specifications.—Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.

S-812 BROCHURE ON LABORATORY SERVICES. 48-page illustrated brochure describes services, facilities and personnel; lists facilities, instruments (includes test instruments) of laboratory available to Government agencies and industry on contact basis.—Cook Research Laboratories, 1157 W. Diversey Pkwy., Chicago 14, Ill.

S-813 COLOR DENSITOMETER. 4-page Bul-

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letin 144 illustrates and describes maker's color densitometer; covers features, operation, application, range.—Macbeth Corp., P. O. Box 950, Newburgh, N. Y.

S-814 D-C. MICROVOLTMETER. 2-page bulletin describes and illustrates maker's "Model MV-15A" d-c. microvoltmeter; covers features, operation, specifications.—Millivac Instrument Corp., P. O. Box 3027, New Haven, Conn.

S-815 TEMPERATURE AND PRESSURE INSTRUMENTS. 4-page bulletin illustrates, describes and gives some applications for several of maker's temperature and pressure instruments (thermometers, recorder-controllers, indicating controllers, viscosimeter, diaphragm motor valves, etc.).—Scientific Instrument Co., Detroit, Mich.

S-816 PERMANENT-MAGNET TYPE SPEAKER. 4-page bulletin describes and illustrates maker's "15-in. Duo-Cone" speaker; covers features, specifications, applications; includes dimensional outlines.—Tube Dep't, Radio Corp. of America, Harrison, N. J.

S-817 LABORATORY APPARATUS. 16-page No. 50-10-40 issue of the "Eberbach Announcer" features article titled "Metallographic Sample Preparation"; also contains items on Buehler metallurgical laboratory apparatus, Burrell high-frequency induction heater, Reco static eliminators for balances and microtomes, Sargent polargraph; encloses 4-page bulletin on International dual-purpose laboratory centrifuge.—Eberbach & Son Co., 200 E. Liberty St., Ann Arbor, Mich.

S-818 KINESCOPE. 4-page bulletin describes and illustrates maker's "19AP4-B" metal-cone type kinescope; covers features, construction, data, and characteristics curves.—Tube Dep't, Radio Corp. of America, Harrison, N. J.

S-819 INSTRUMENT PIPING VALVES. 4-page bulletin illustrates and describes maker's valves for instrument piping and general use; covers features, types, ratings, connections, dimensions.—Jerguson Gage & Valve Co., 80 Fellsway, Somerville 45, Mass.

S-820 "TAYLOR TECHNOLOGY." 28-page Vol. 3, No. 2 issue of this house organ features articles titled "Ammonium Nitrate Production Requires Automatic Controls," "High Capacity Positioner Provides Faster Action of Large Valves," "Characteristics of Automatic Control Responses," "Shop Facilities for Testing Pressure Instruments—Part I," and others.—Taylor Instrument Companies, Rochester 1, N. Y.

S-821 PHOTOELECTRIC MICROPHOTOMETER. 2-page bulletin describes and illustrates Hilger non-recording photoelectric microphotometer, matching microphotometers, and "Galvoscale" reflecting galvanometer for use with microphotometer.—The Jarrell Ash Co., 165 Newbury St., Boston, Mass.

S-822 PROJECTION KINESCOPE. 12-page bulletin illustrates and describes maker's "7NP4" projection kinescope; covers features, engineering data, installation and application.—Tube Dep't, Radio Corp. of America, Harrison, N. J.

S-823 WIND-TEMPERATURE RECORDER. 4-page No. 34 issue of "The Hydromike" pictures and describes maker's "Type QAWT" wind-temperature recorder for use at sites that cannot be visited easily or often; also features pictorial article titled "Rivers of Oregon—The McKenzie."—Leupold & Stevens Instruments, Inc., 4445 N.E. Glisan St., Portland 13, Ore.

S-824 AUTOMATIC POSITIONING DEVICES. 48-page looseleaf-bound folder describes and illustrates maker's "Autotune" automatic tuning, positioning and repositioning devices, control units, stepping motors, etc.; includes article "Automatic Positioning Control Mechanisms" reprinted from ELECTRONIC INDUSTRIES, Jan. 1946.—Collins Radio Co., Cedar Rapids, Iowa.

S-825 MULTIPLIER PHOTOTUBE. 8-page bulletin describes and illustrates maker's "5819" 10-stage head-on type multiplier phototube; covers features, data, general considerations, application and installation.—Tube Dep't, Radio Corp. of America, Harrison, N. J.

S-826 TOOLMAKER MICROSCOPE. 4-page bulletin illustrates and describes maker's "Model No. 1" toolmaker microscope; covers advantages, features, applications and specifications.—Boeckeler Instrument Co., 31 E. Rillito St., Tucson, Ariz.

S-827 GLIDE SLOPE RECEIVER. 4-page bulletin describes and illustrates maker's

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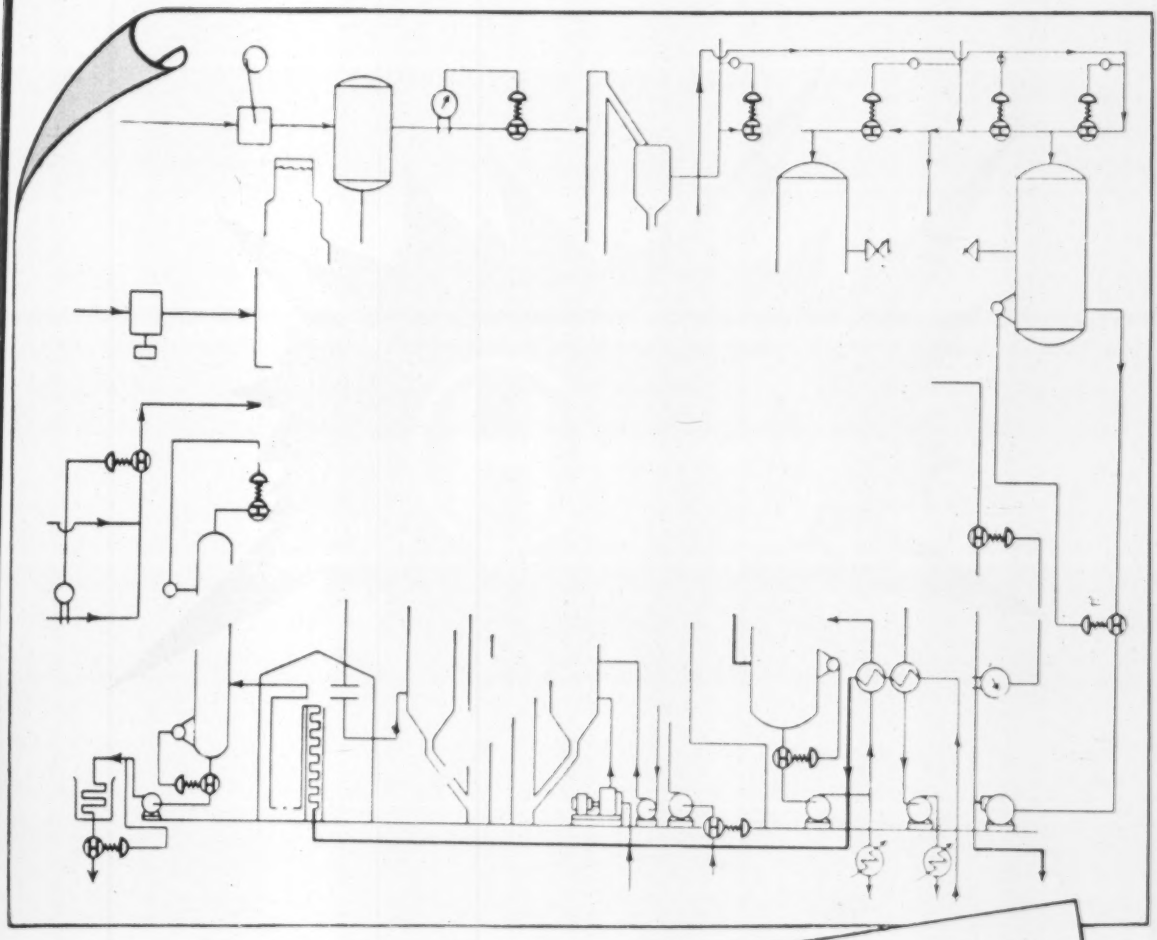

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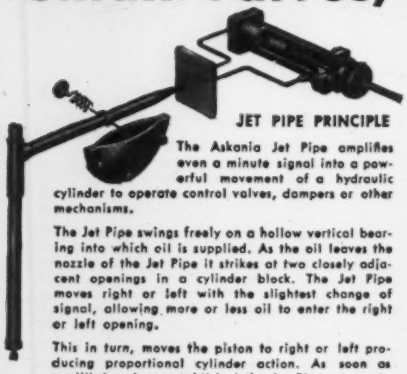

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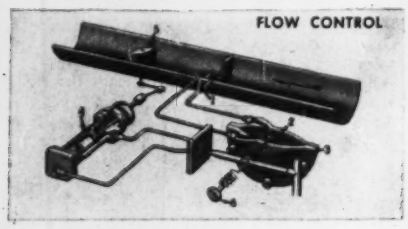
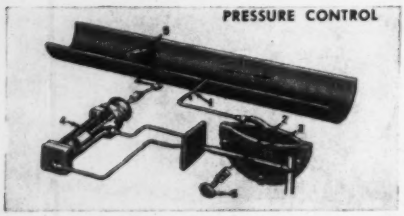
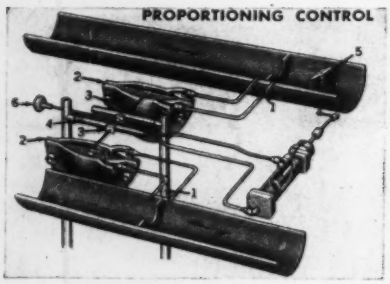


Differential pressure (1), measured by diaphragm (2). Flow changes deflect Jet Pipe (3), causing proportional cylinder movement (4), and positioning of valve (5). Setting-Dial for desired flow (6).



Pressure (1), measured by diaphragm (2). Pressure changes deflect Jet Pipe (3), causing proportional cylinder movement (4), and positioning of valve (5). Setting-Dial for desired pressure (6).



Differential pressures (1), measured by individual diaphragms (2). Signal transmitted to opposite sides of Jet Pipe (3). Any unbalance deflects Jet Pipe (4), causing proportional cylinder movement and positioning of valve (5). Setting-Dial for ratio (6).

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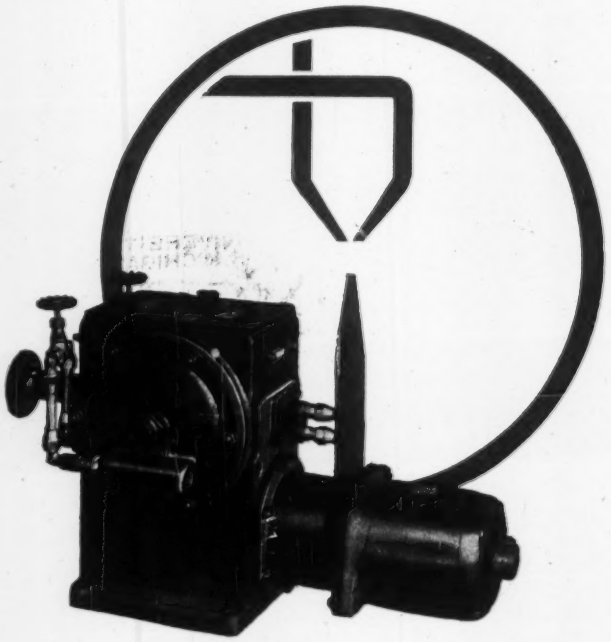

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